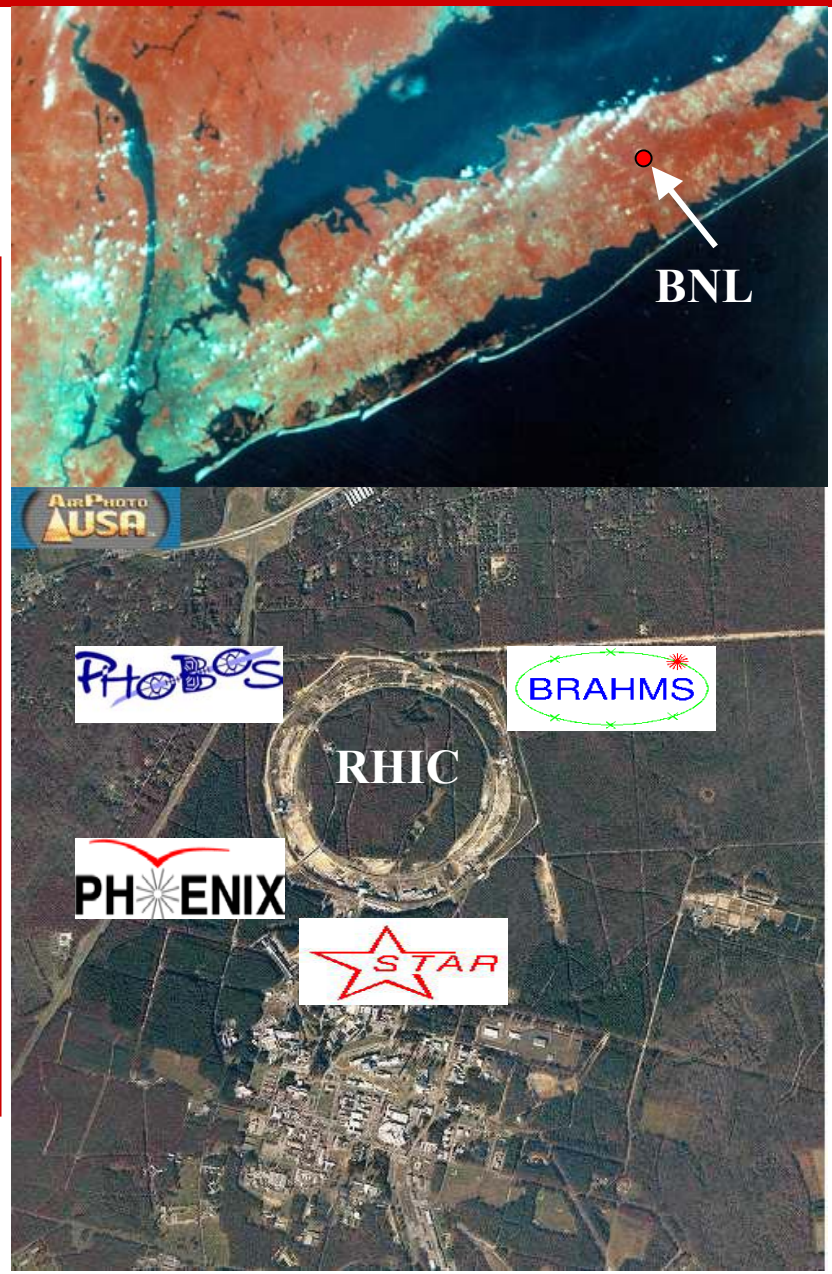
The RHIC Experiments

Dr. Edward J. O'Brien
Brookhaven National Laboratory

VCI2004, Vienna, Austria
February 16-21, 2004

The Relativistic Heavy Ion Collider at BNL

- Two independent rings 3.83 k in circumference
  - 120 bunches/ring
  - 106 ns crossing time
- Maximum Energy
  - $s^{½}$ = 500 GeV p-p
  - $s^{½}$ = 200 GeV/N-N Au-Au
- Design Luminosity
  - Au-Au $2x10^{26}$ $cm^{-2}s^{-1}$
  - p - p $2x10^{32}$ $cm^{-2}s^{-1}$ (polarized)
- Capable of colliding any nuclear species on any other nuclear species



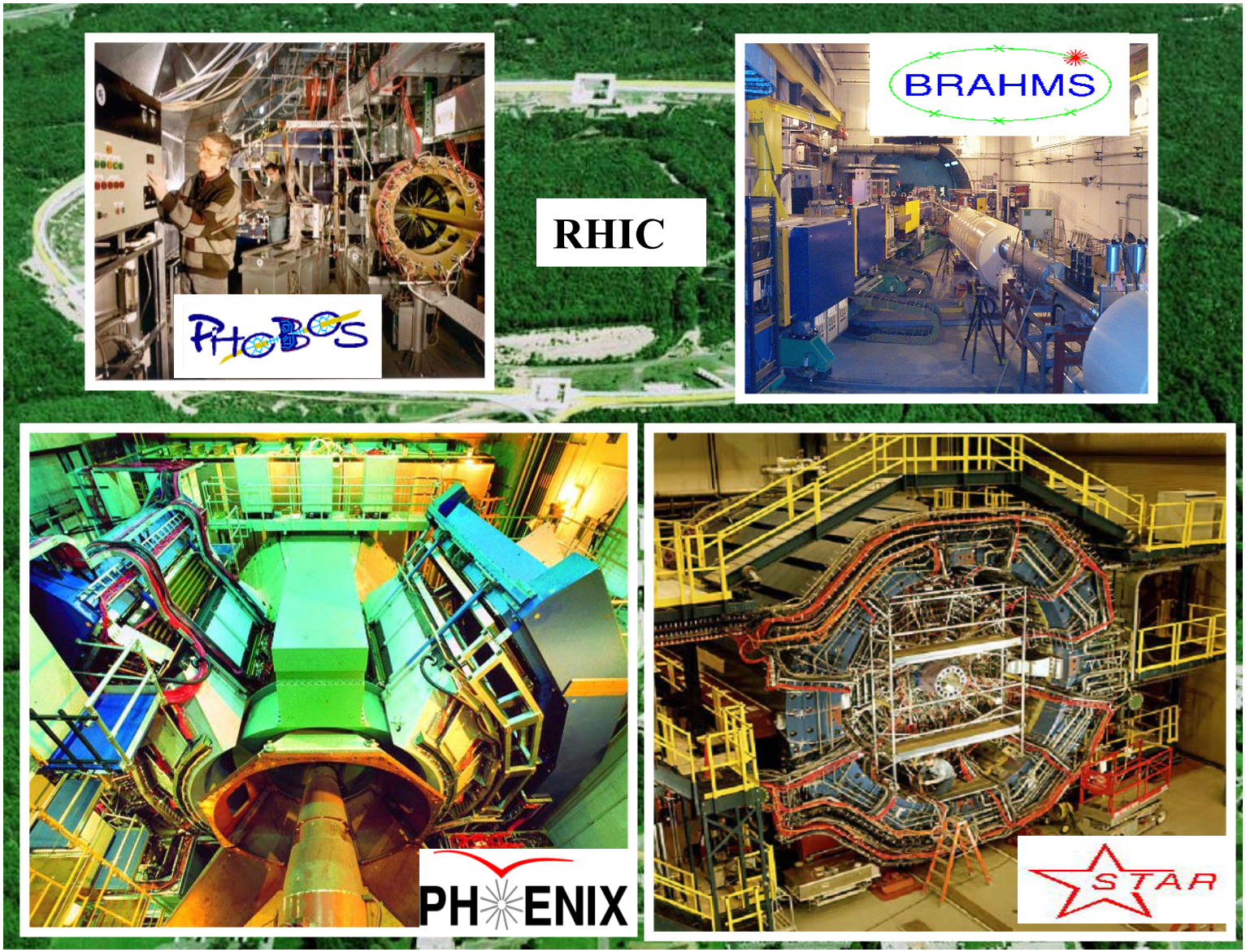
The RHIC Run History

The RHIC machine performance has been very impressive:

- Machine is delivering design luminosity(+) for AuAu
- Collided 3 different species in 4 years
  - AuAu, dAu, pp
- 3 energies run
  - 19 GeV, 130 GeV, 200 GeV
- 1st operation of a polarized hadron collider

PHENIX	Year	Species	$s^{1/2}$ [GeV]	$\int Ldt$	N_{tot} (sampled)	Data Size
Run1	2000	Au-Au	130	1 μb^{-1}	10M	3 TB
Run2	2001/02	Au-Au	200	24 μb^{-1}	170M	10 TB
		Au-Au	19	------	<1M	
		p-p	200	0.15 pb^{-1}	3.7G	20 TB
Run3	2002/03	d-Au	200	2.74 nb^{-1}	5.5G	46 TB
		p-p	200	0.35 pb^{-1}	6.6G	35 TB
Run4	2003/04	Au-Au	200	80 μb^{-1}	500M+ ongoing	70 TB
		p-p	200			

The RHIC Experiments



RHIC Physics Program

Heavy Ion Physics:

- **Quark Gluon Plasma & hot dense nuclear matter**
  - **Particle mult., E_T, single particle spectra, particle correlations, vector mesons, strange baryons, heavy quarks, photons (direct & virtual)…**

Polarized Protons:

- **Nucleon Spin**
  - **Gluon spin: ΔG, sea quark spin: $\Delta\bar{u}$, $\Delta\bar{d}$. Nucleon transverse spin distr.**

Proton-Nucleus:

- **Structure function physics**
  - **Gluon structure function saturation, shadowing, anti-shadowing…**

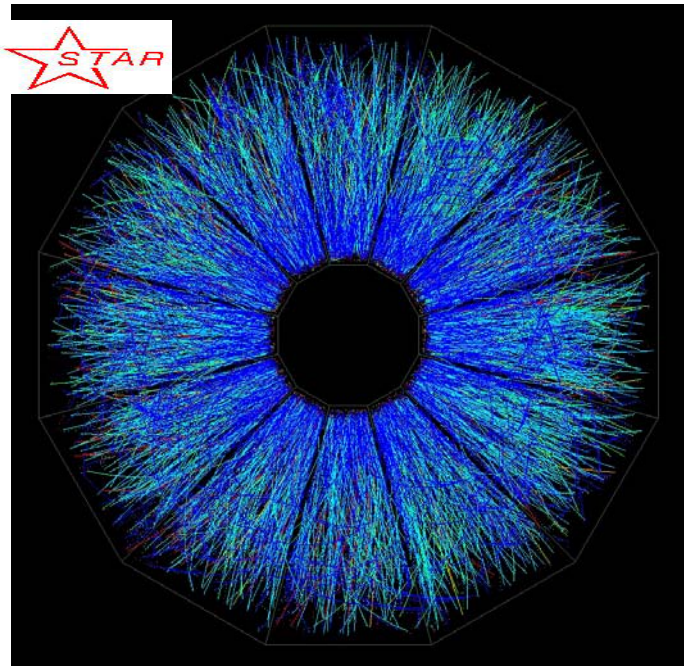
What have the four RHIC experiments (BRAHMS, PHENIX, PHOBOS, STAR) measured at RHIC so far ?

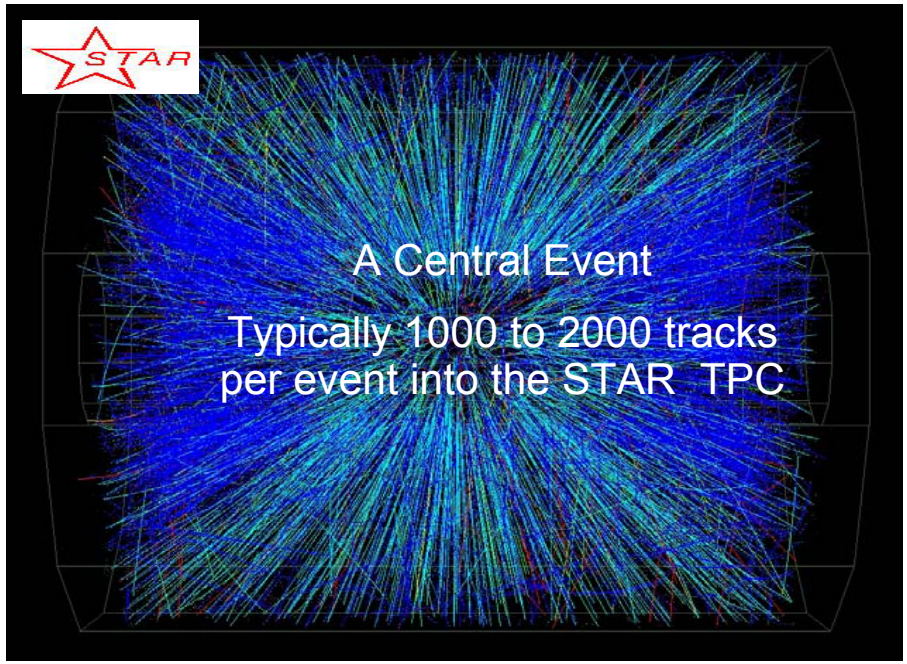
γ, $e^{\pm}$, $\mu^{\pm}$, $\pi^{\pm}$, π^0, $K^{\pm}$, $K^{*0}(892)$, K_s^0, η, p, d, ρ^0, ϕ, Δ,

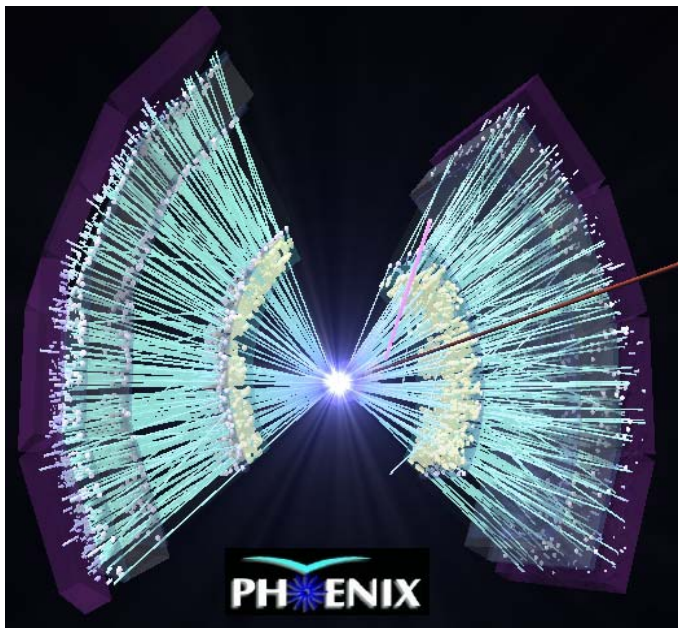
Λ, $\Sigma^*(1385)$, $\Lambda^*(1520)$, $\Xi^{\pm}$, Ω, D^0, $D^{\pm}$, D^*, J/Ψ's,

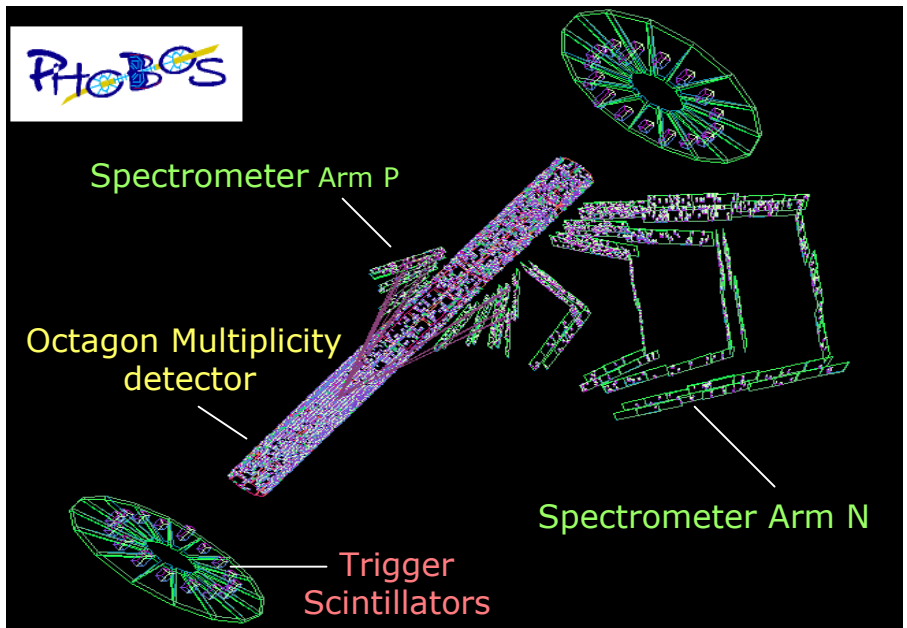
(+ anti-particles) …

Au on Au Central Collision Event

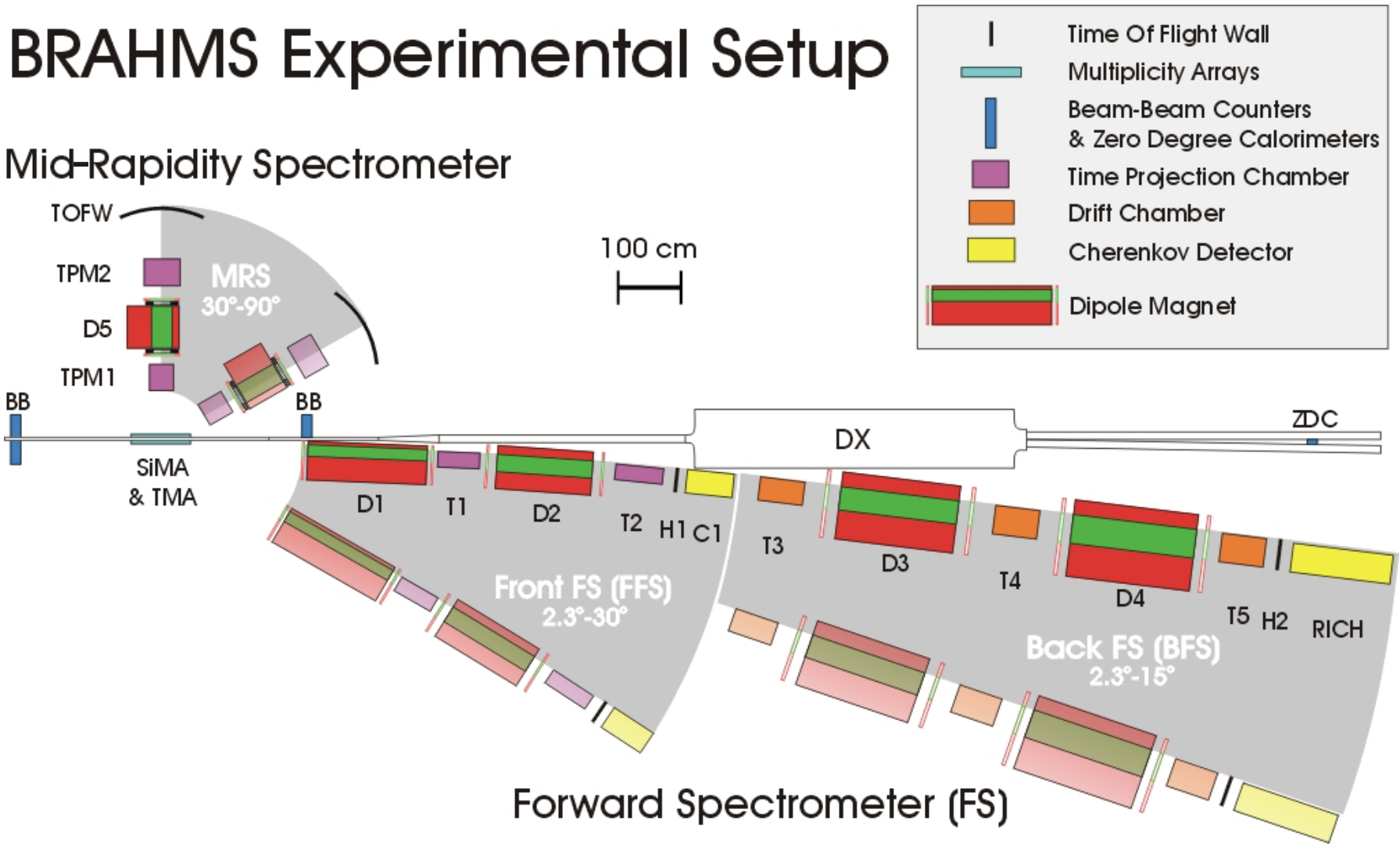








The BRAHMS Detector



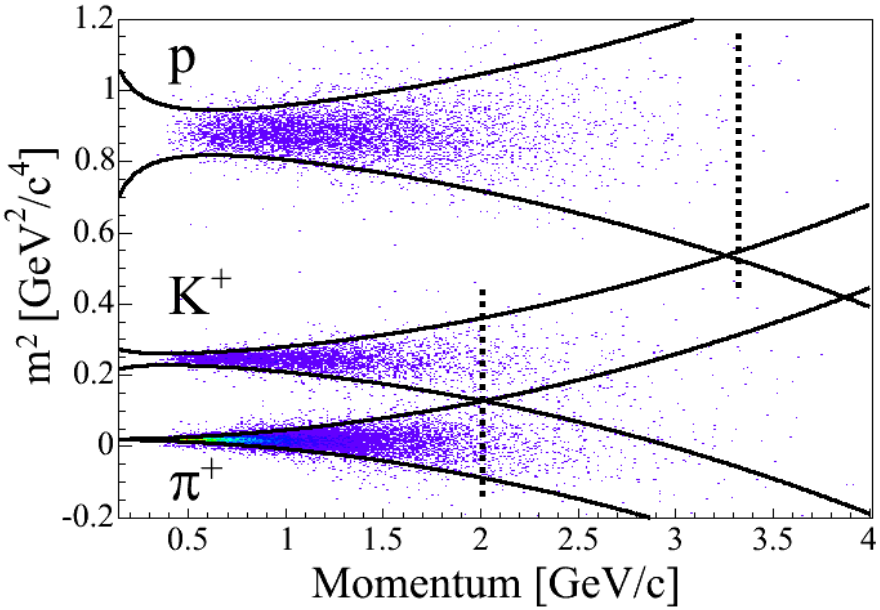
Brahms Particle Identification

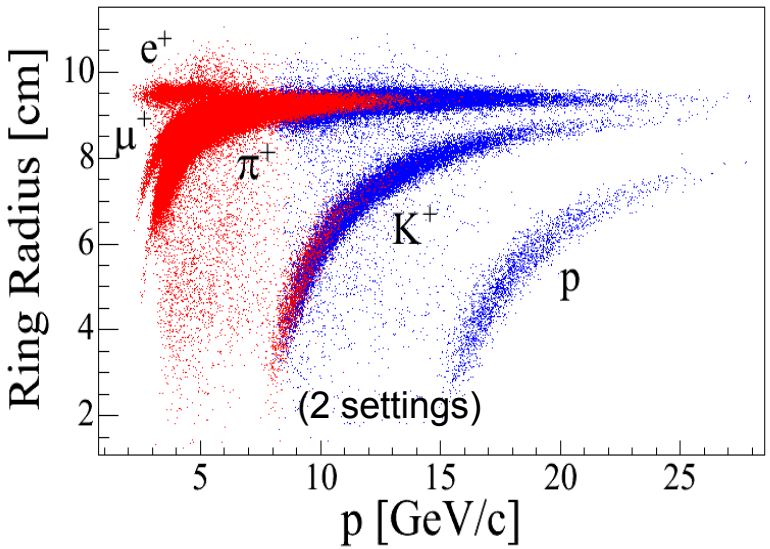
TIME-OF-FLIGHT

$$m^2 = p^2\left(\frac{c^2 TOF^2}{L^2} - 1\right)$$

Particle Separation: p_{max} (2σ cut)=

2σ cut	TOFW	TOF1	TOF2
π / K	2 GeV/c	3 GeV/c	4.5 GeV/c
K / p	3.5GeV/c	5.5GeV/c	7.5GeV/c





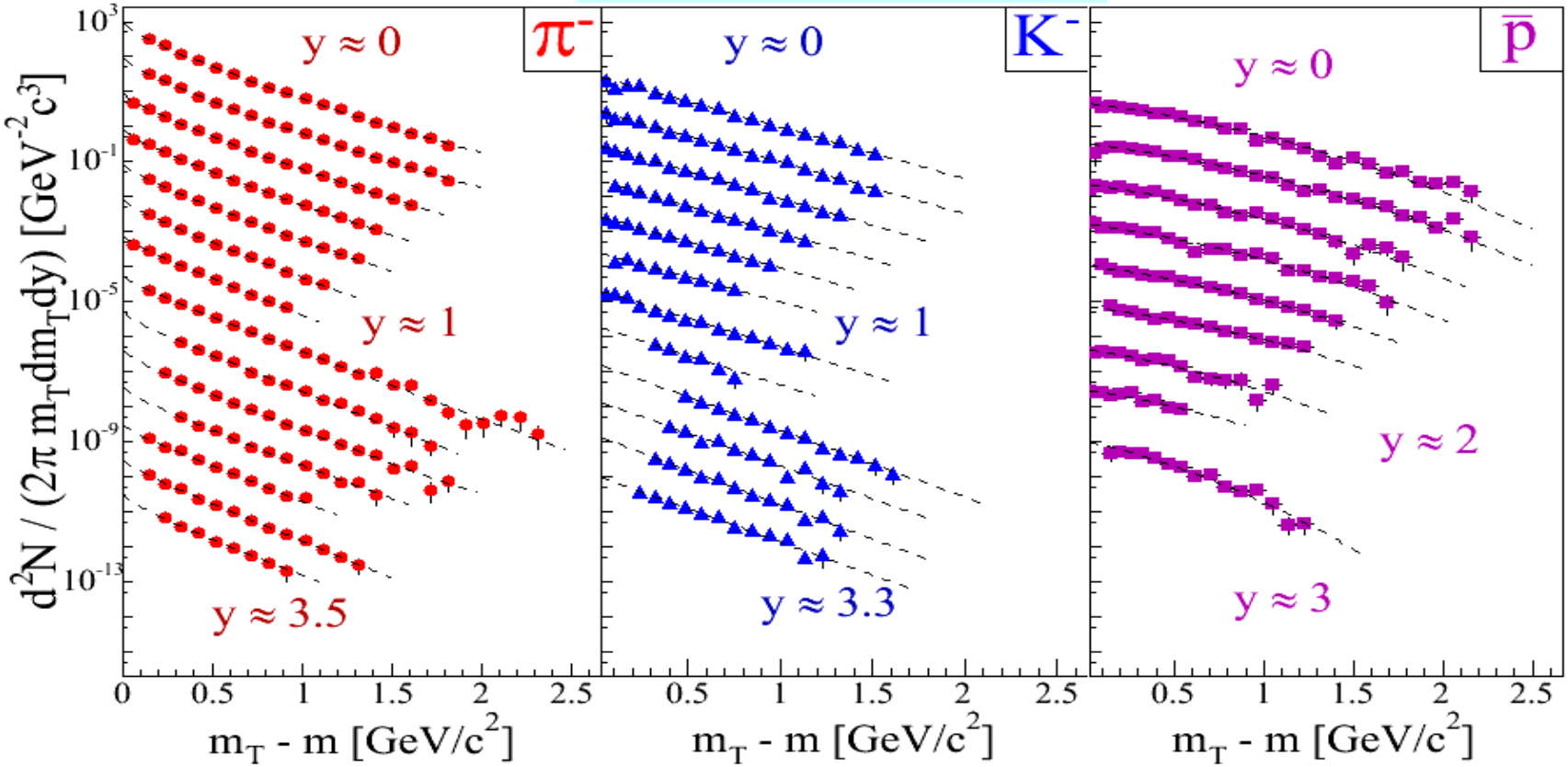
CHERENKOV

RICH: Cherenkov light focused on spherical mirror → ring on image plane

Ring radius vs momentum gives PID
π / K separation 20 GeV/c
Proton ID up to 35 GeV/c

Brahms Particle Spectra

Top 5% central collisions



Pions: power law

$$A\left(1+\frac{p_T}{p_0}\right)^{-n}$$

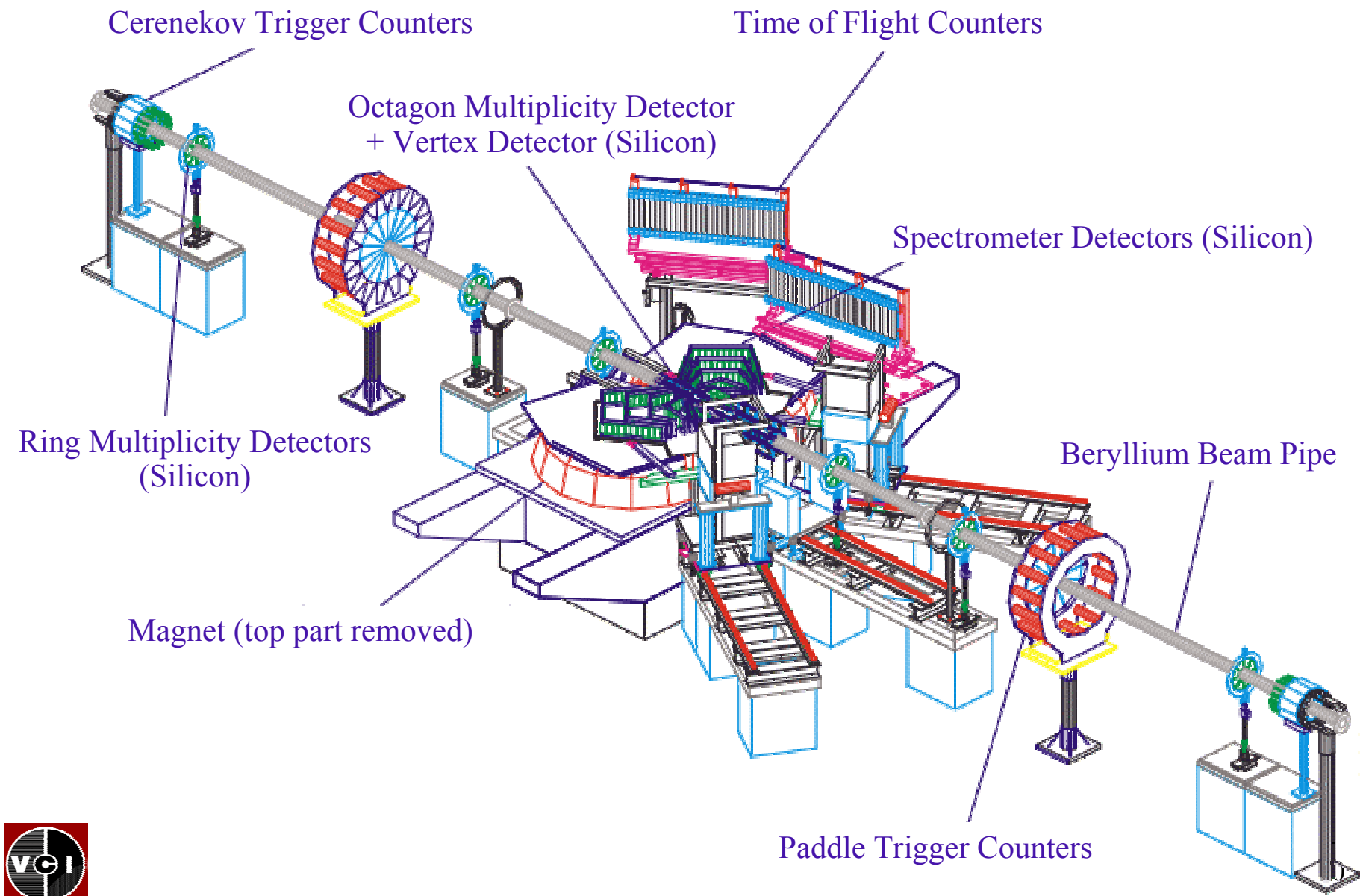
Kaons: exponential

$$A\exp\left(-\frac{m_T-m}{T}\right)$$

Protons: Gaussian

$$A\exp\left[-\frac{p_T^2}{2\sigma^2}\right]$$

The PHOBOS Detector

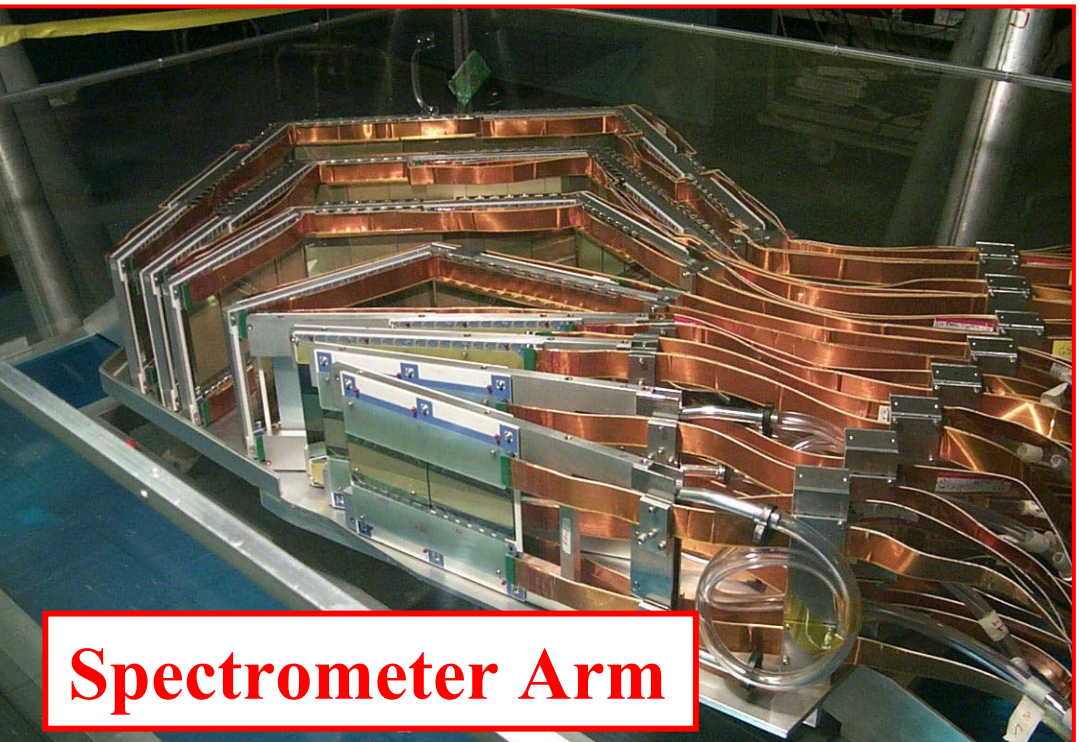


Silicon Everywhere

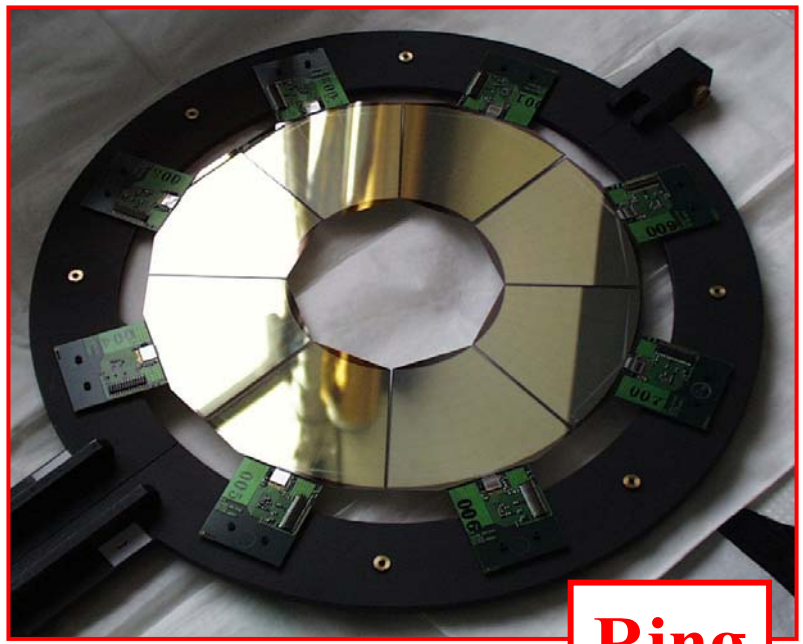
Octagon/Vertex

137,000 channels in total

Strips and Pads



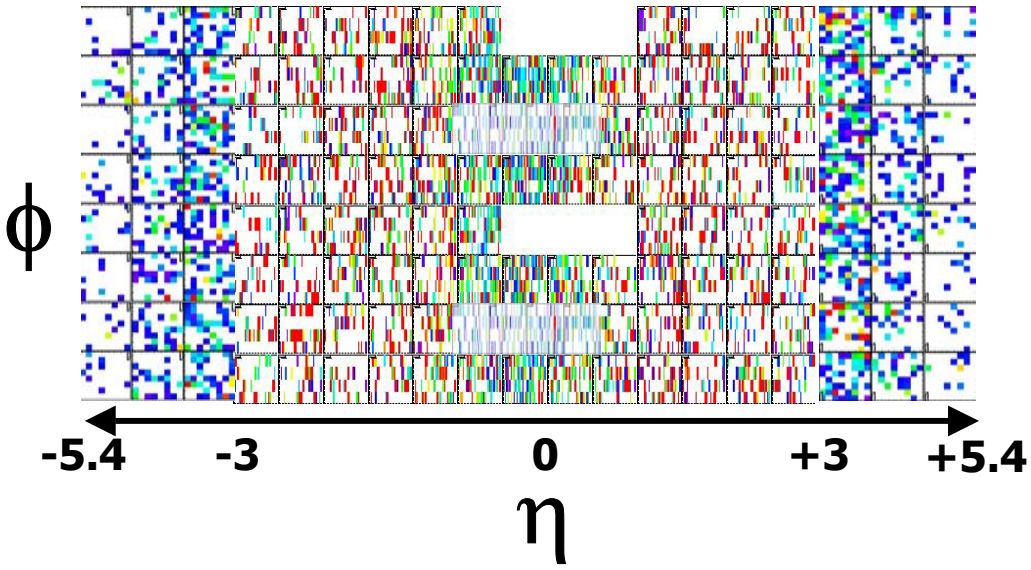
Spectrometer Arm



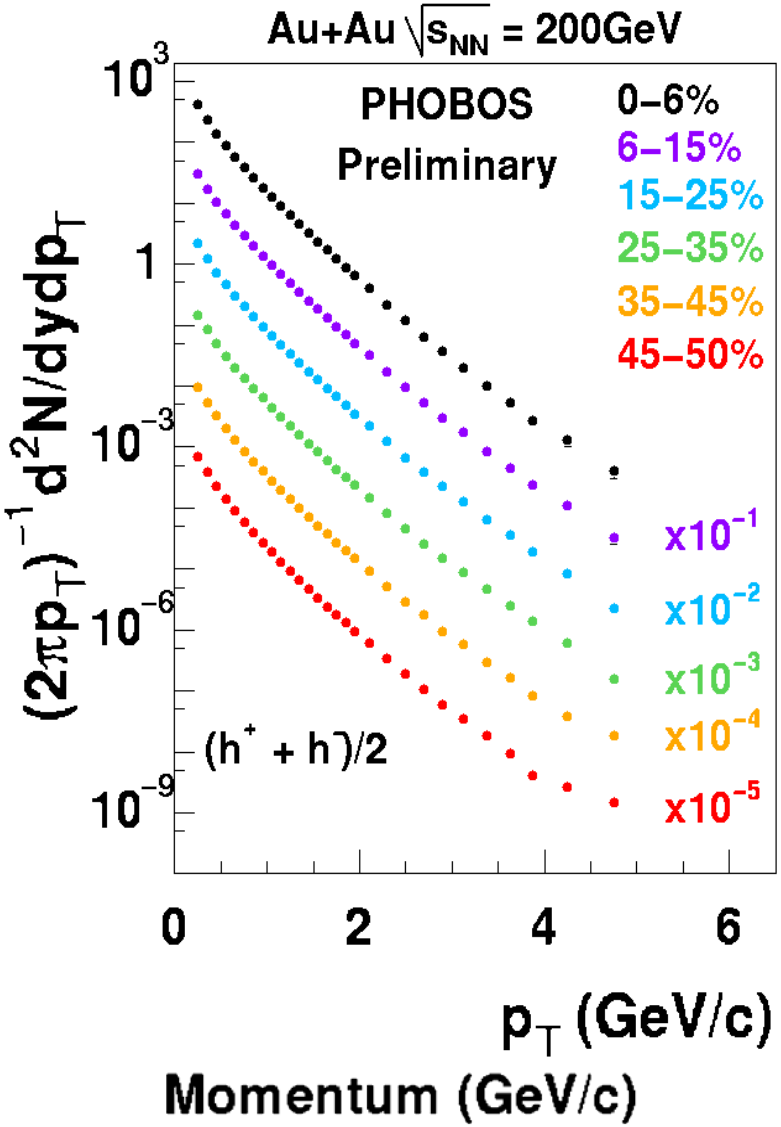
Ring

Hits and Tracks in PHOBOS

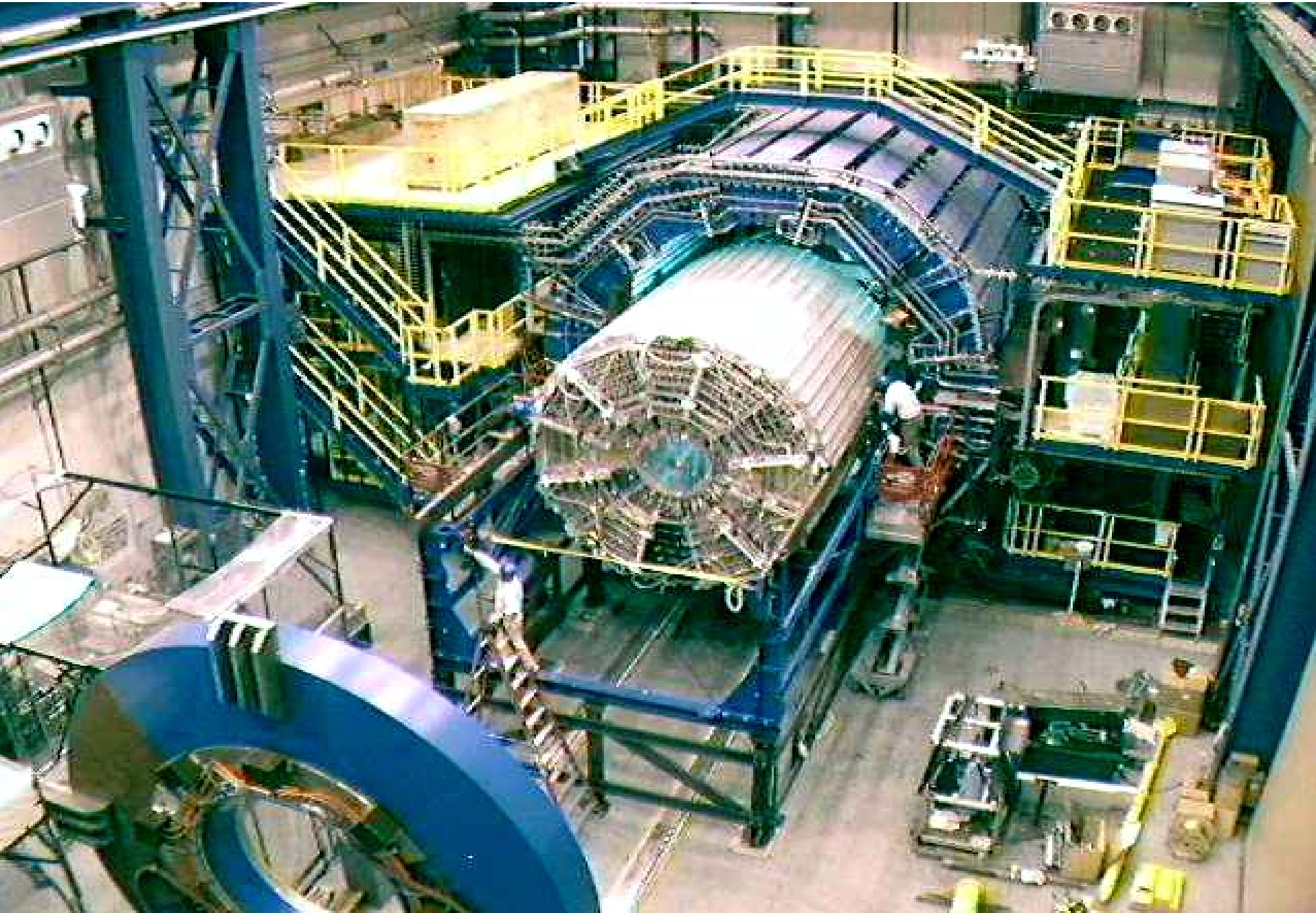
Nearly 4π Coverage



Distribution of hits and energy deposition → dN/dη

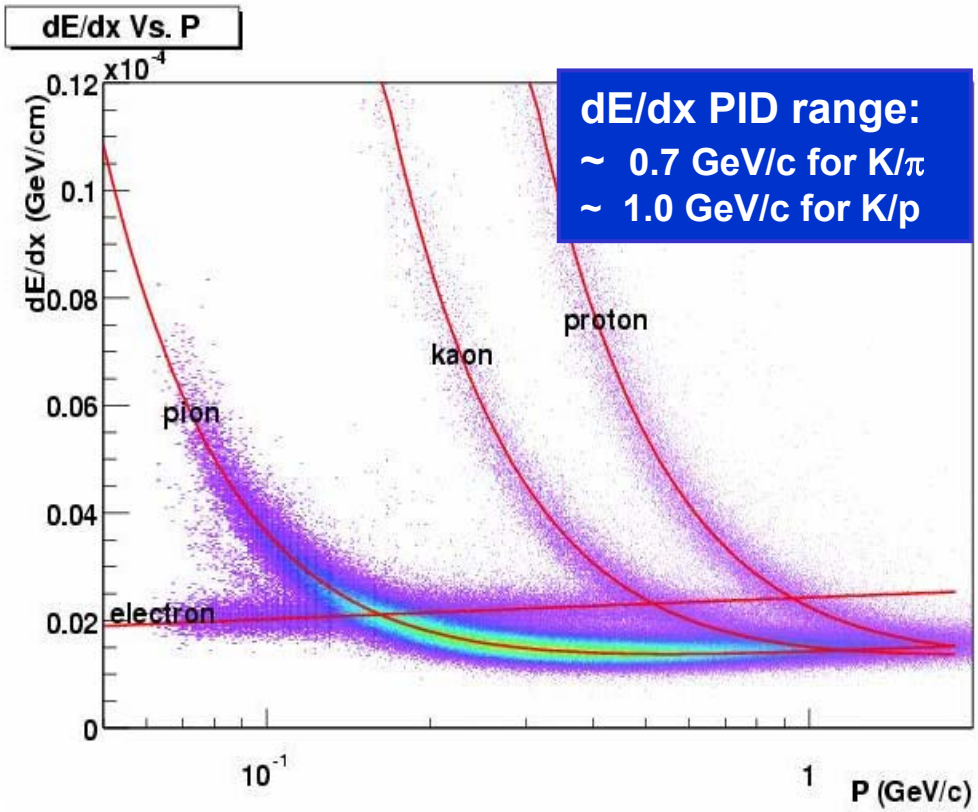


The STAR Detector



TPC Gas Volume & Electrostatic Field Cage

- Two-track separation 2.5 cm
- Momentum Resolution < 2%
- Space point resolution ~ 500 mm



Self supporting Inner Field Cage:
Al on Kapton using Nomex honeycomb; 0.5% rad length

- Gas: P10 (Ar-CH_4 90%-10%) @ 1 atm
- Voltage : - 28 kV at the central membrane
  135 V/cm over 210 cm drift path

Particle ID using Topology & Combinatorics

Secondary vertex:

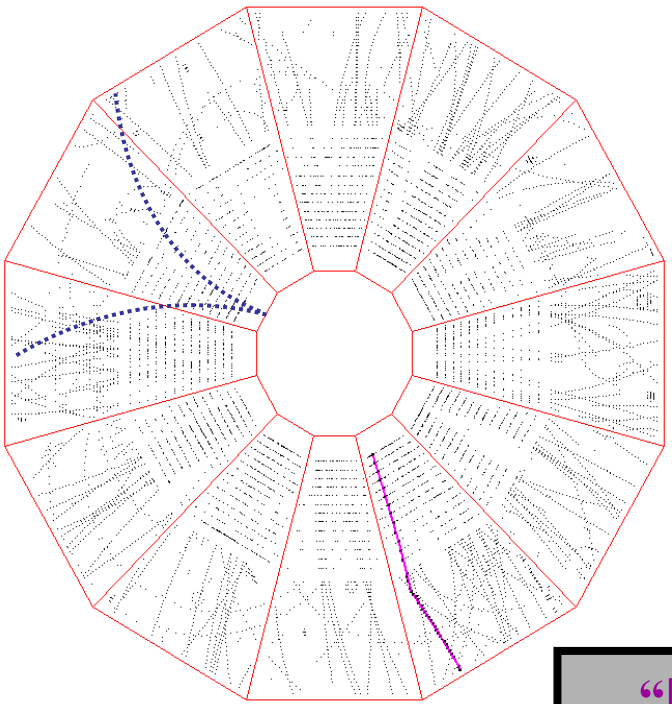
$K_s \rightarrow \pi + \pi$ $\quad \Lambda \rightarrow p + \pi$

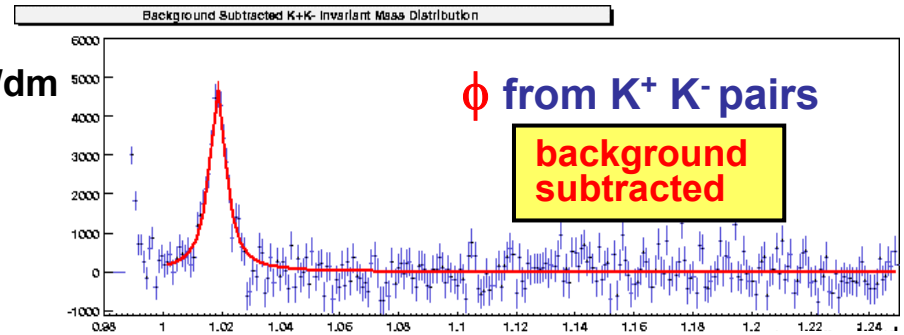
$\Xi \rightarrow \Lambda + \pi$ $\quad \Omega \rightarrow \Lambda + K$

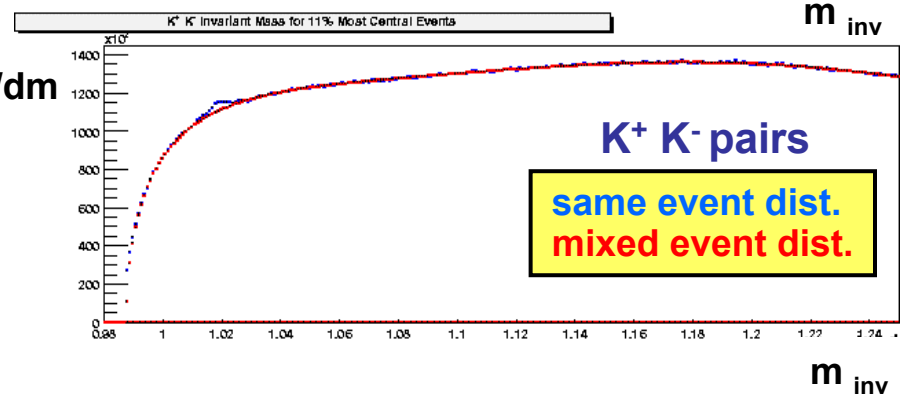
$\gamma \rightarrow e^+ + e^-$

$K_s \rightarrow \pi^+ + \pi^-$ $\quad \phi \rightarrow K^+ + K^-$

$\Lambda \rightarrow p + \pi^-$ $\quad \rho \rightarrow \pi^+ + \pi^-$



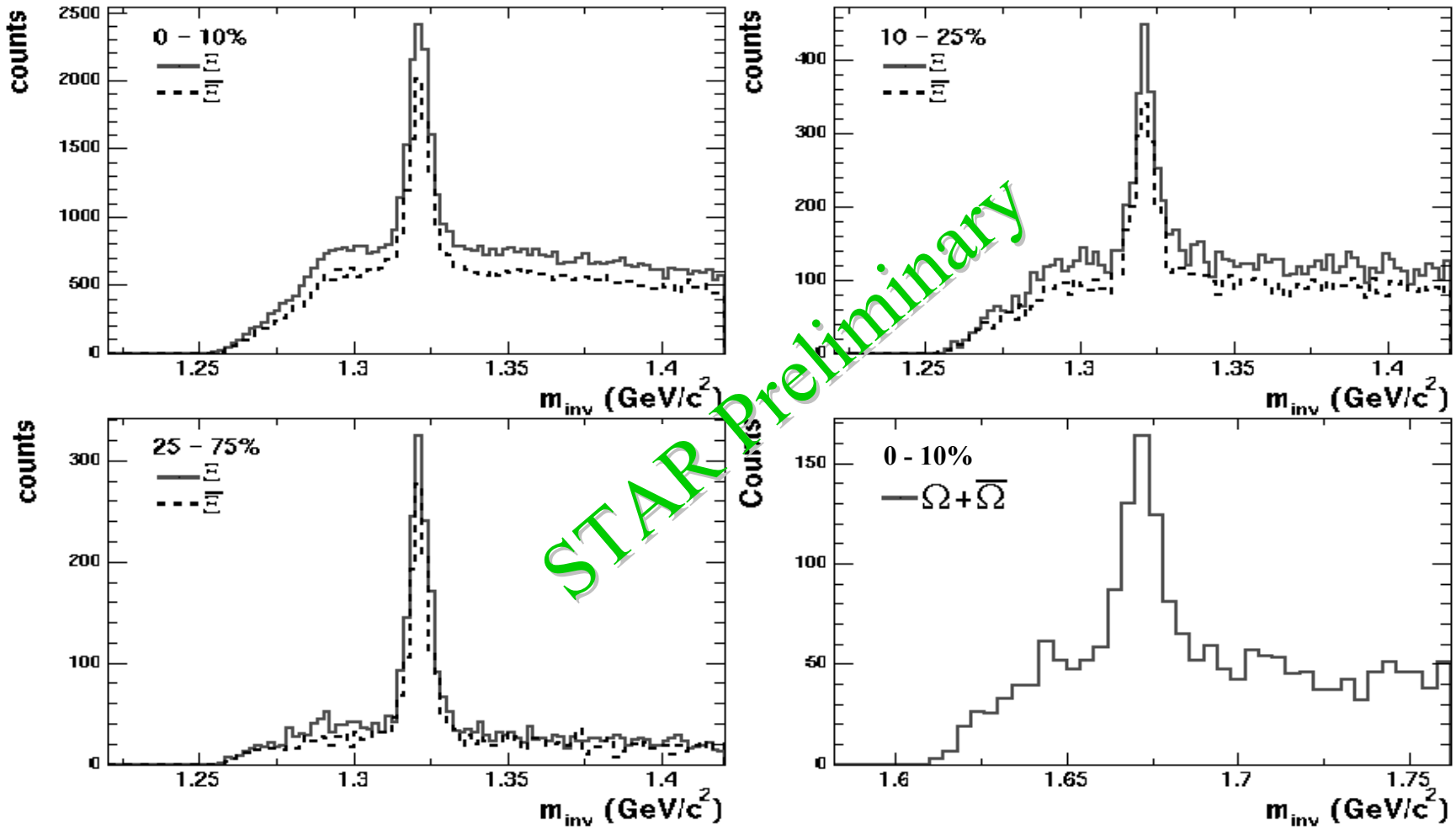




"kinks"

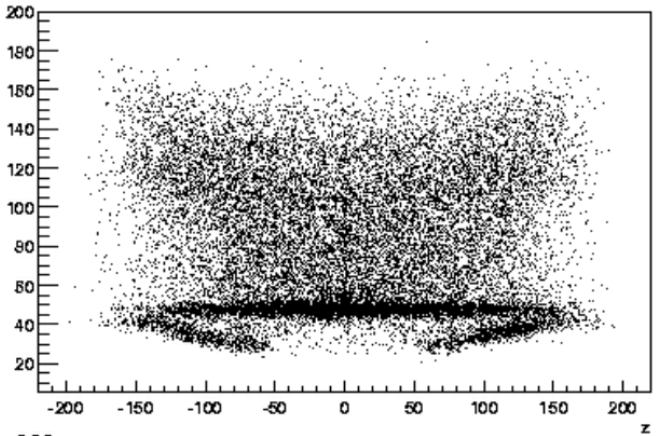
$K^{\pm} \rightarrow \mu^{\pm} + \nu$

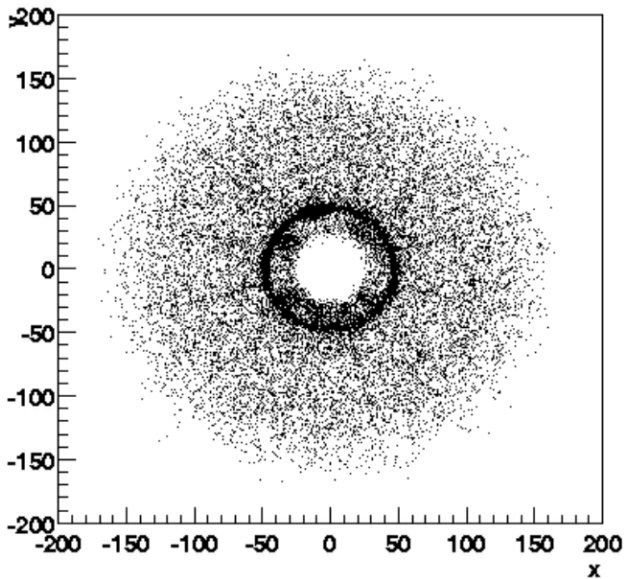
Multi-strange Baryons

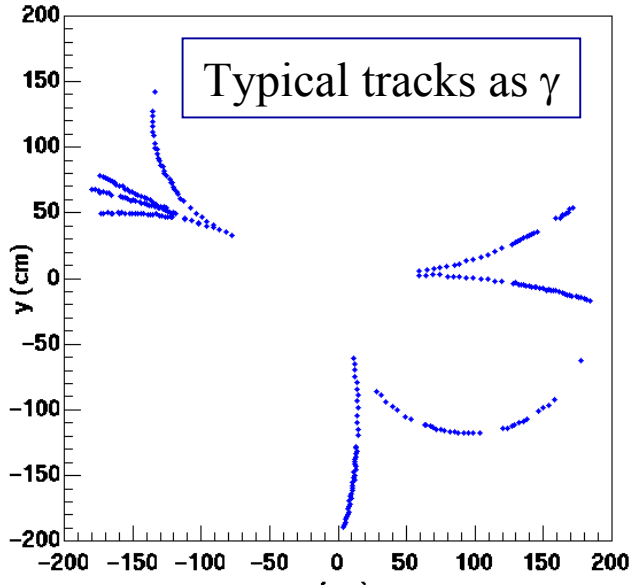


Photon and π^0 ID

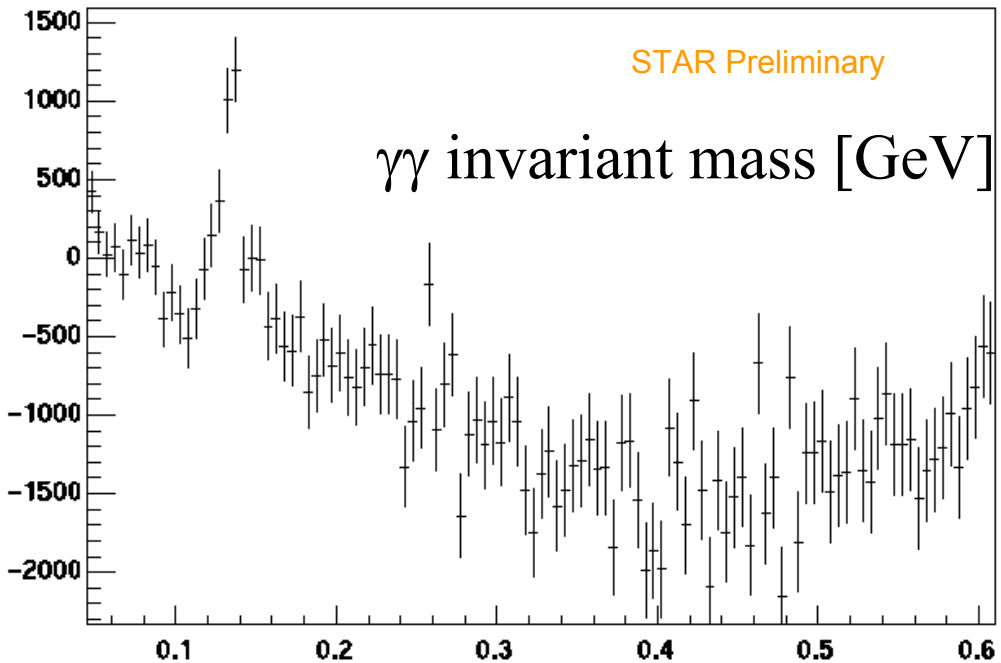
- The e^+e^- pair from γ conversion
- Large p_T coverage of γ measurement
  - from 50 MeV/c to 4 GeV/c







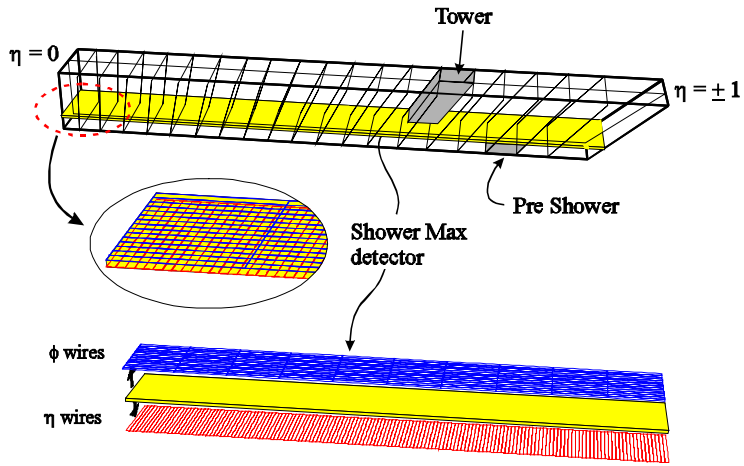
π^0

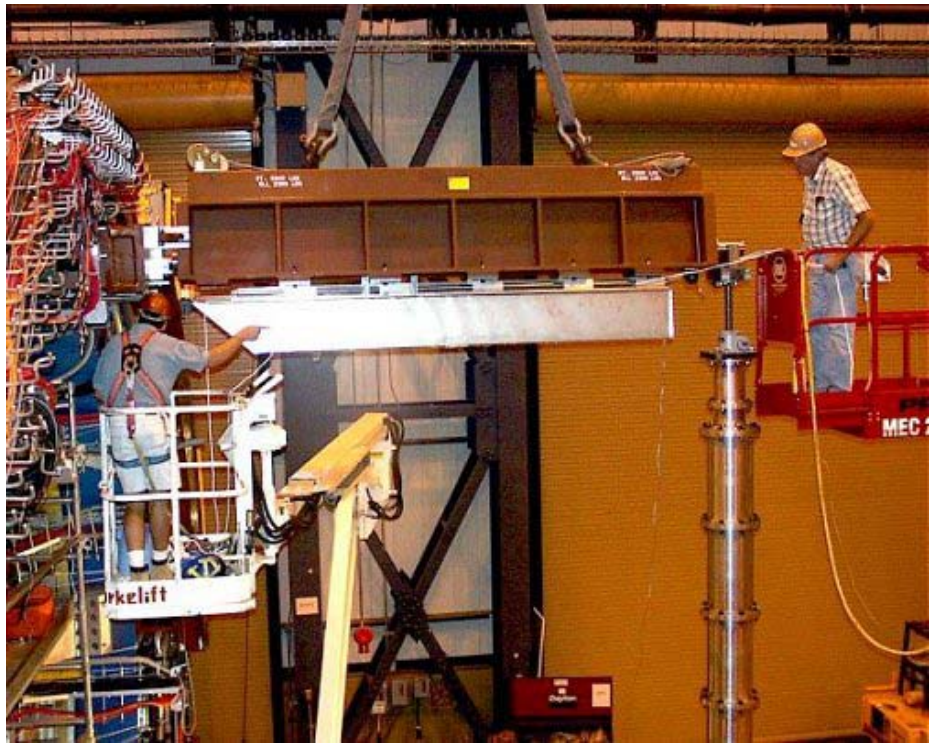


The STAR electromagnetic calorimeter

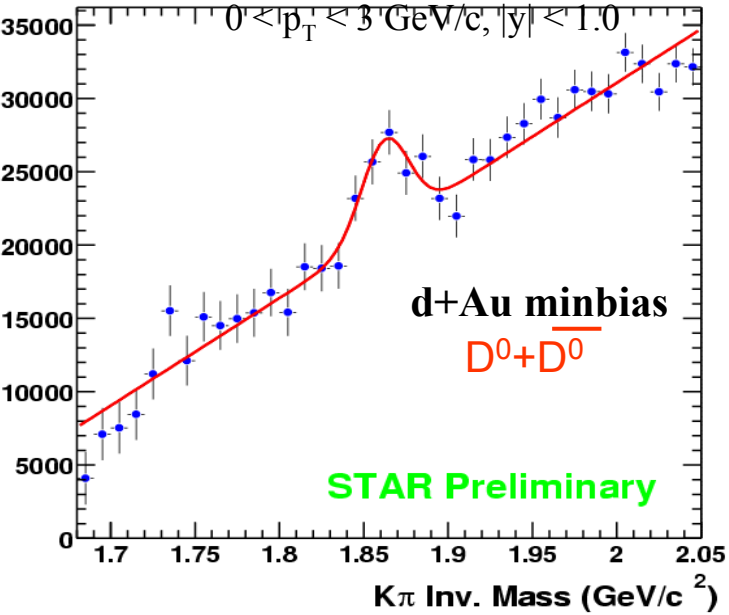
Year 2003 barrel EMC

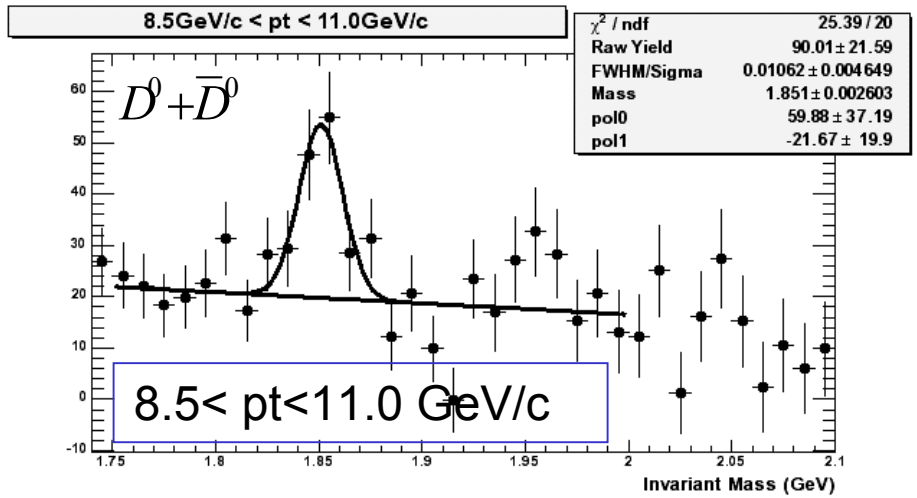
- p+p and d+Au runs at 200 GeV/A
- $0 < \eta < 1.0$
- Full azimuthal coverage
- 60 modules
- 40 towers/module
  - 21 X_0
  - $(\Delta\eta, \Delta\phi)_{tower} \sim (0.05, 0.05)$
  - $\delta E/E \sim 16\%/\sqrt{E}$
- Shower max detector
  - Positioned at ~ 5 X_0
  - Larger spatial resolution
  - $(\Delta\eta, \Delta\phi) \sim (0.007, 0.007)$

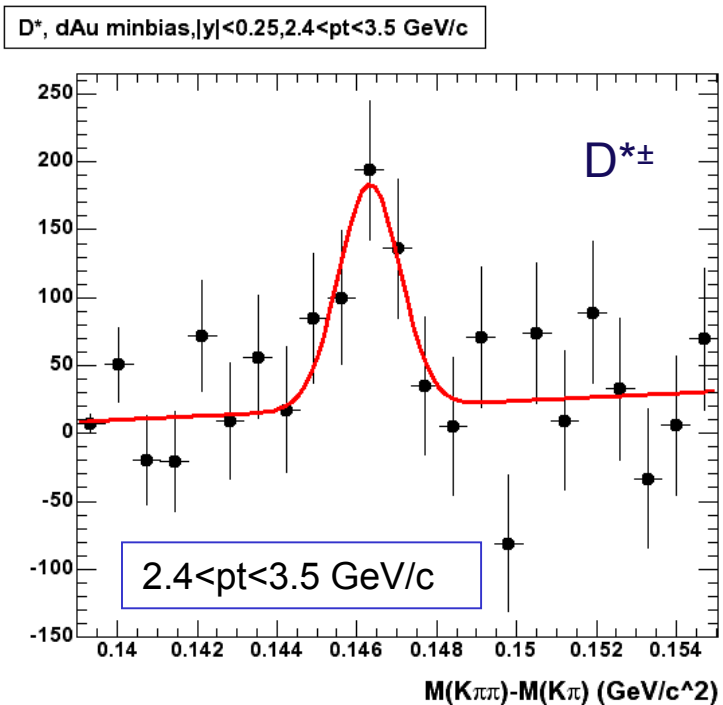


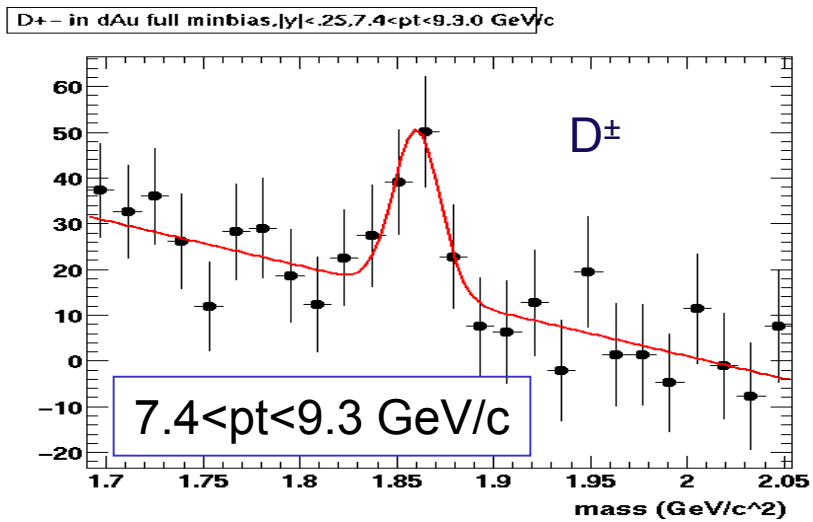


STAR D^*, D^0, $D^\pm$ signal









The PHENIX Detector

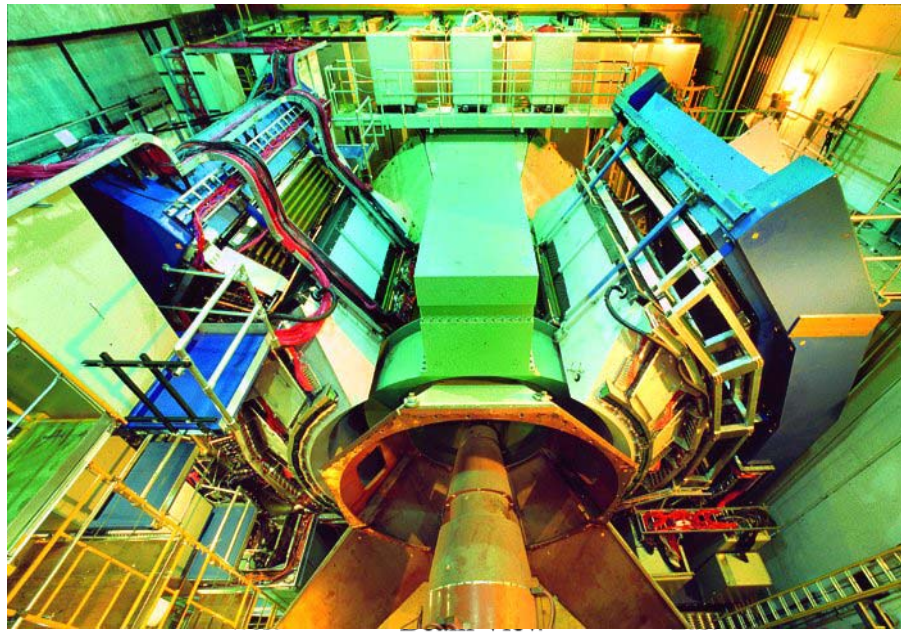
- Detector Redundancy
- Fine Granularity, Mass Resolution
- High Data Rate
- Good Particle ID
- Limited Acceptance

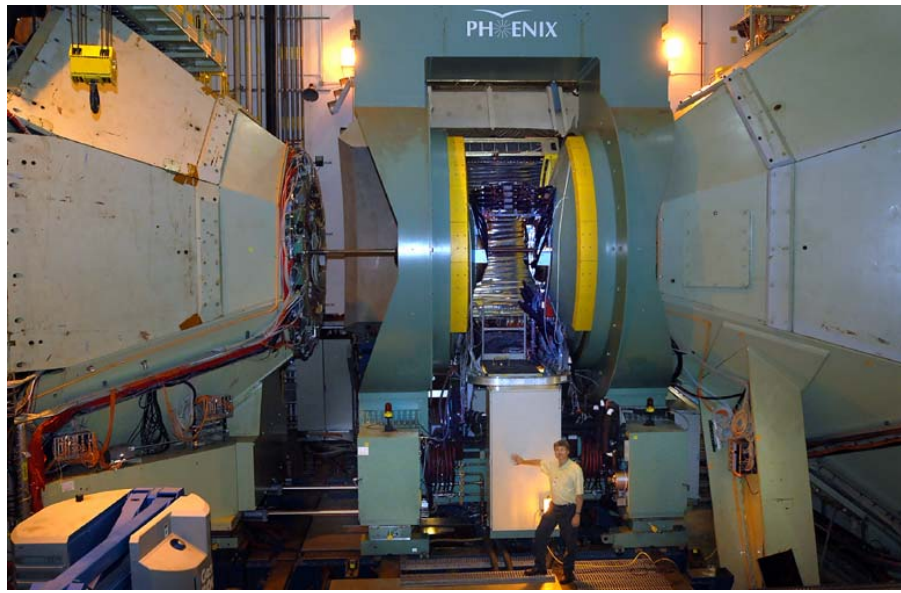
Charged Particle Tracking:
- Drift Chamber
- Pad Chamber
- Time Expansion Chamber/TRD
- Cathode Strip Chambers

Particle ID:
- Time of Flight
- Ring Imaging Cerenkov Counter
- TEC/TRD
- Muon ID (PDT's)

Calorimetry:
- Pb Scintillator
- Pb Glass

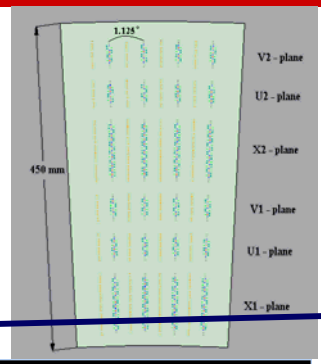
Event Characterization:
- Multiplicity Vertex Detector (Si Strip,Pad)
- Beam-Beam Counter
- Zero Degree Calorimeter/Shower Max Detector
- Forward Calorimeter
- Normalization Trigger Counters

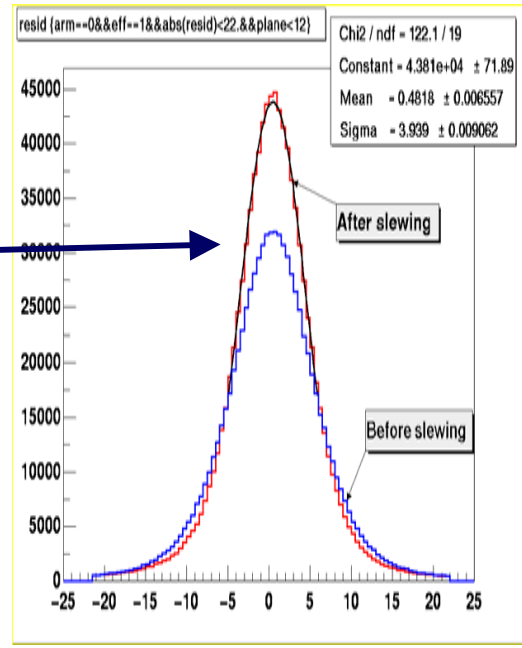




Central Tracking: Drift Chamber

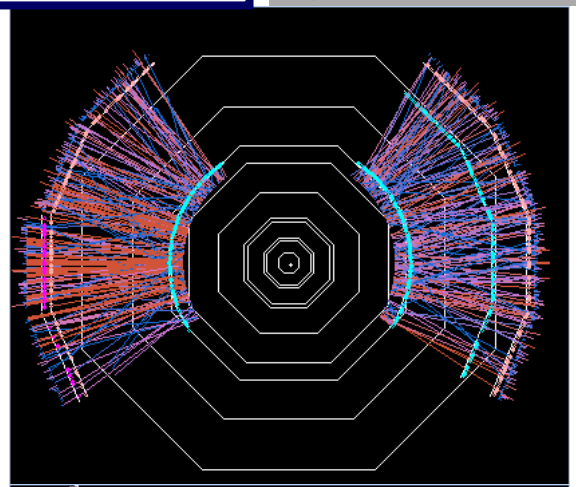
- Jet -chamber anode/cathode structure modified for HI high multiplicity
- Joint Russia/US design & construction
- All Titanium frame
- σ_x = 120 μm , two-track sep = 2mm

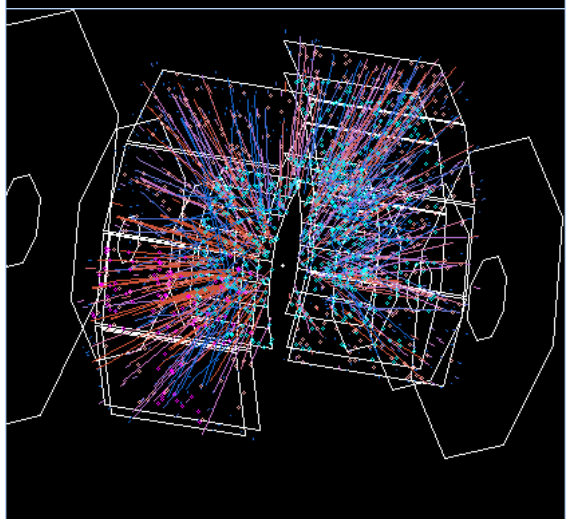


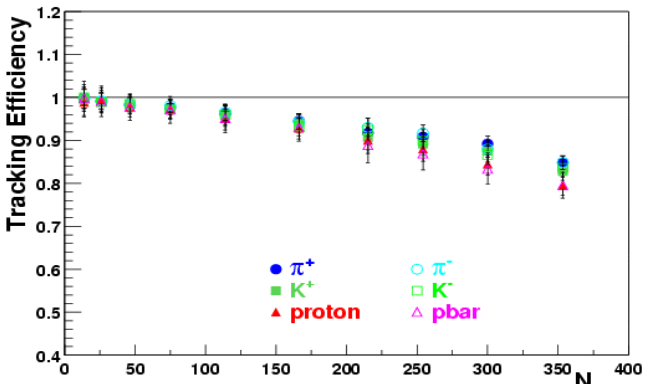


DC Position Resolution

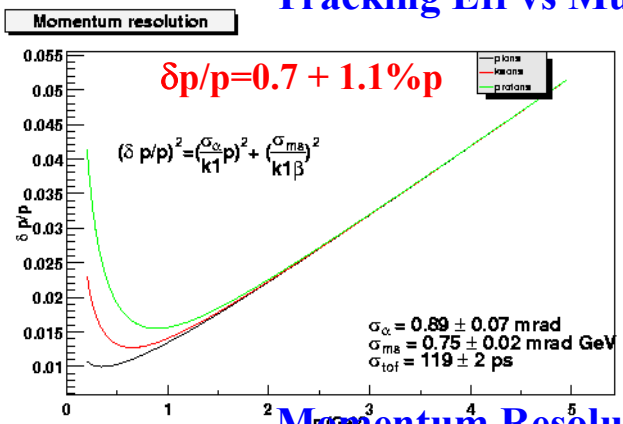
Central Au Au Event







Tracking Eff vs Mult.

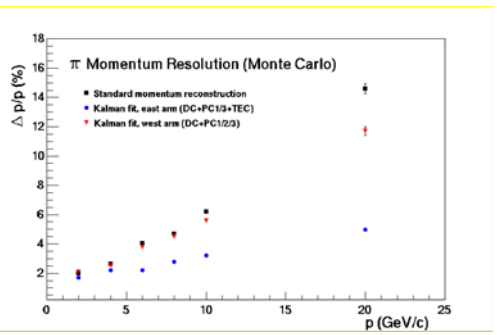


Momentum Resolution

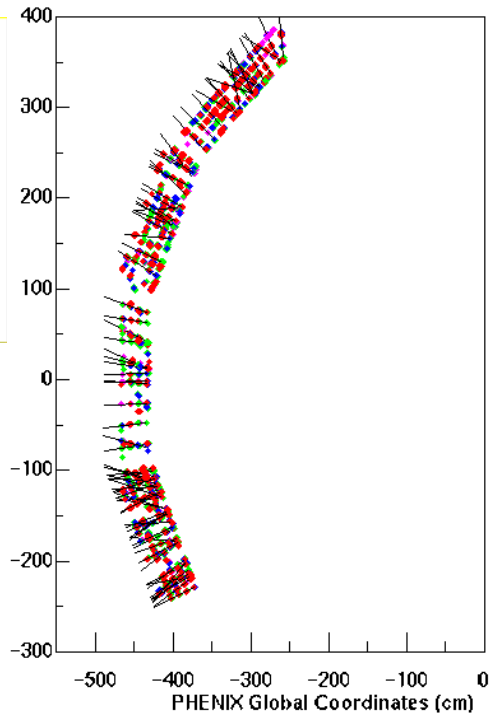
DC wires with kapton wire dividers

Central Tracking: Time Expansion Chamber

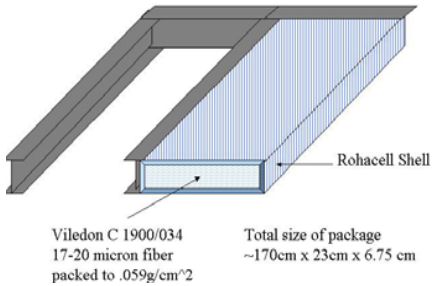
- 24 TEC Chambers arranged in 4, 6-Chamber sectors
- Used for tracking and PID (dE/dx,TR). σ_x = 260 μm
- dE/dx: e/π = 5% at 500 MeV/c (4 pls), e/π = 1.5% (6pls)
  Important for momentum resolution $p_T > 4.0$ GeV/c
- TR polypropylene fiber/foam radiator packs installed

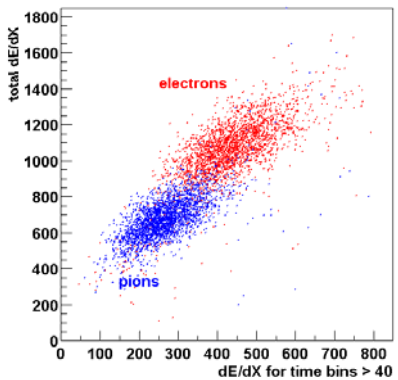


Momentum Resolution

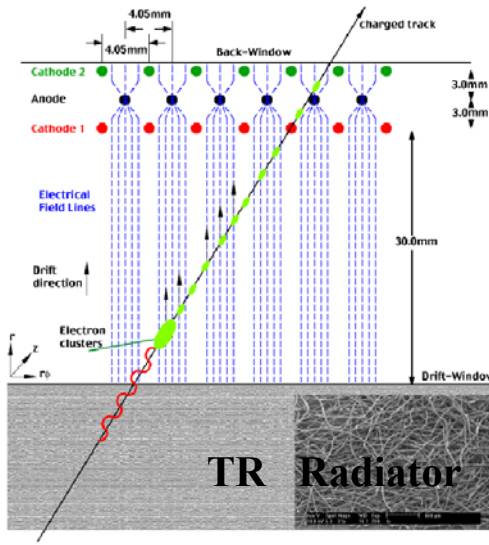


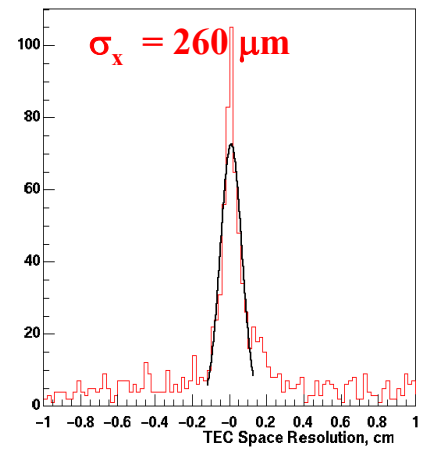
Tracks in TEC from Central Au-Au Collisions





e/π Separation using TR & dE/dx

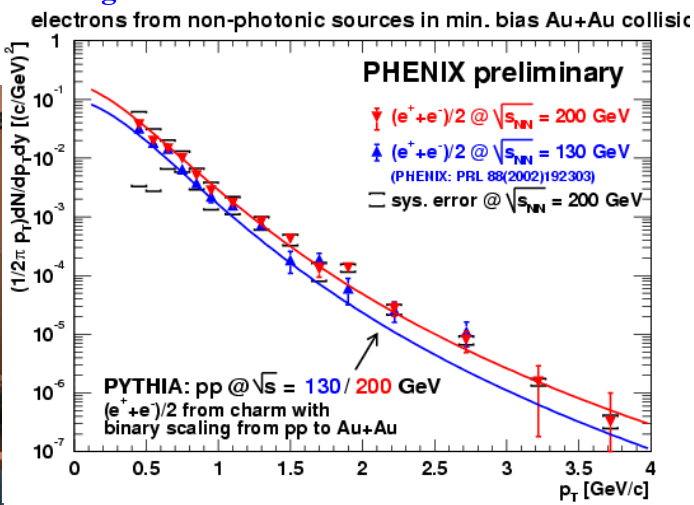


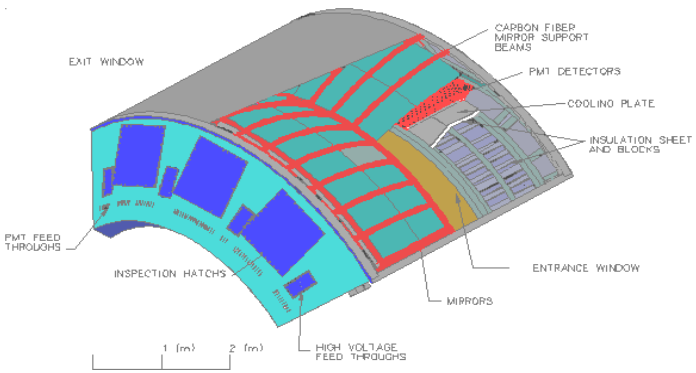


Particle ID Detectors: RICH

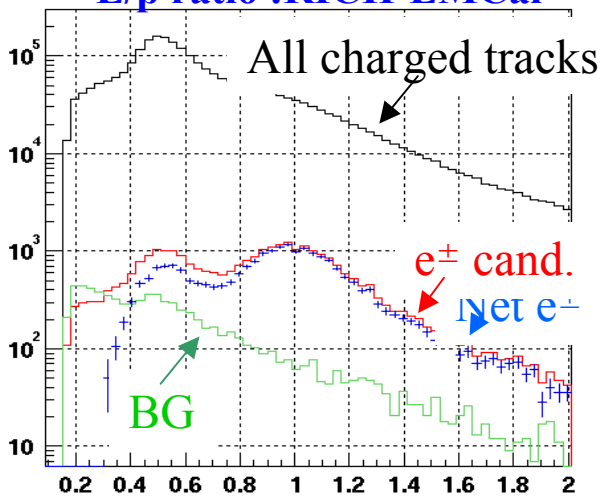
- Gas radiator CO_2, e/π separation for $p < 5$ GeV/c
- 5120 PMTs sensitive to single photoelectrons, $\sigma_t < 1$ ns
- Ring resolution ~1° in both Φ and η

Charm signal measured in PHENIX Central Arms



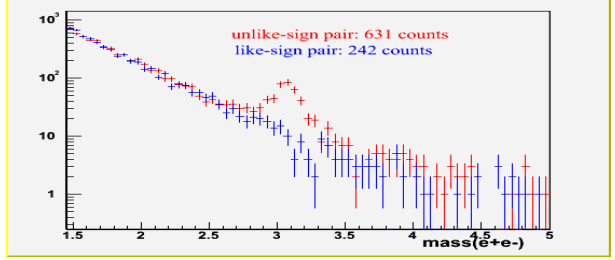


E/p ratio :RICH-EMCal

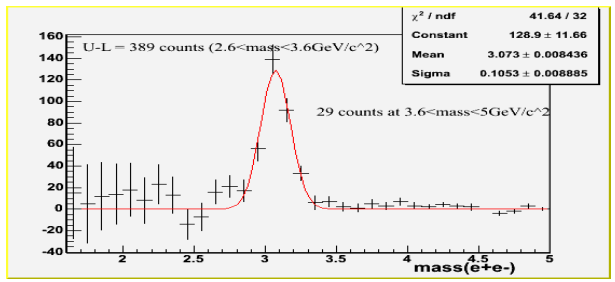


Energy/momentum (E/p)

J/ψ from dAu

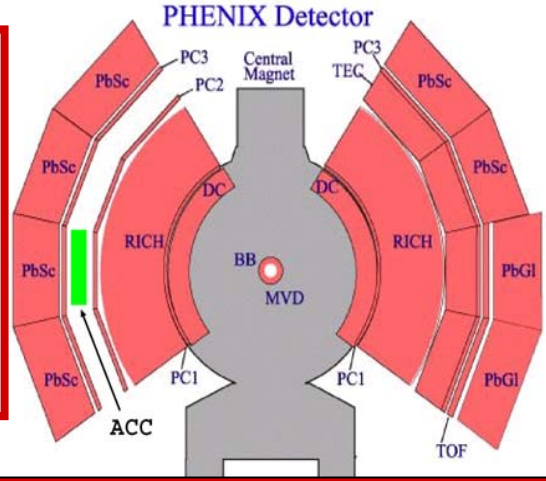


Mass Resolution ~ 100 MeV

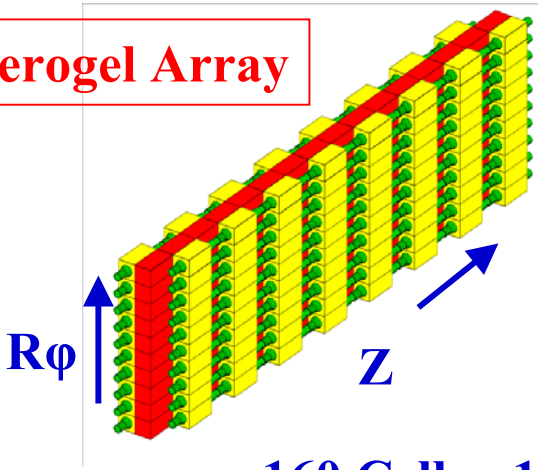


Aerogel Sector in PHENIX

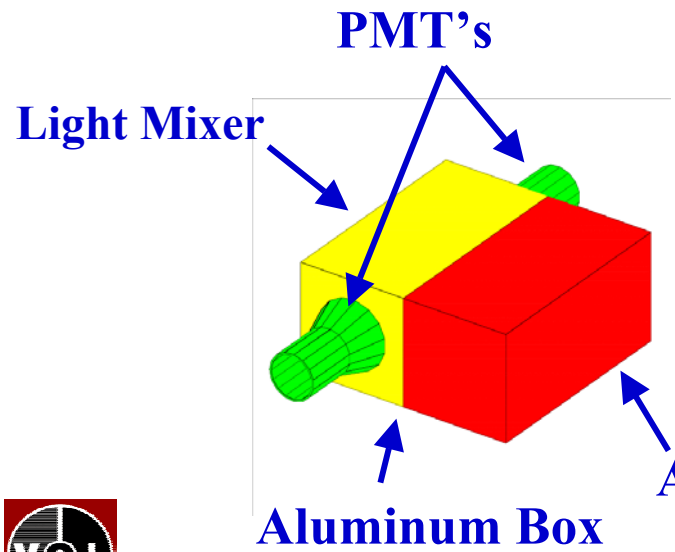
- Install 4 m^2 Aerogel array by 2005
  - 2 m^2 array is installed now
- Aerogel is SiO_2-based material
- Index n= 1.0114
- Additional TOF (mRPC) array to be installed behind Aerogel
- Particle ID to > 8 GeV/c for π, K, p



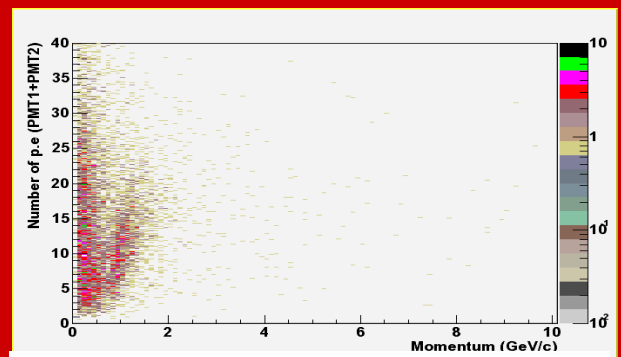
Aerogel Array

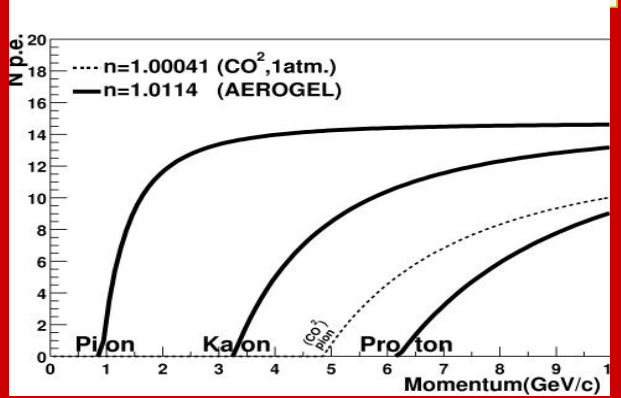


160 Cells : 16 x 10



Aerogel Cell (11x22x11 cm^3)



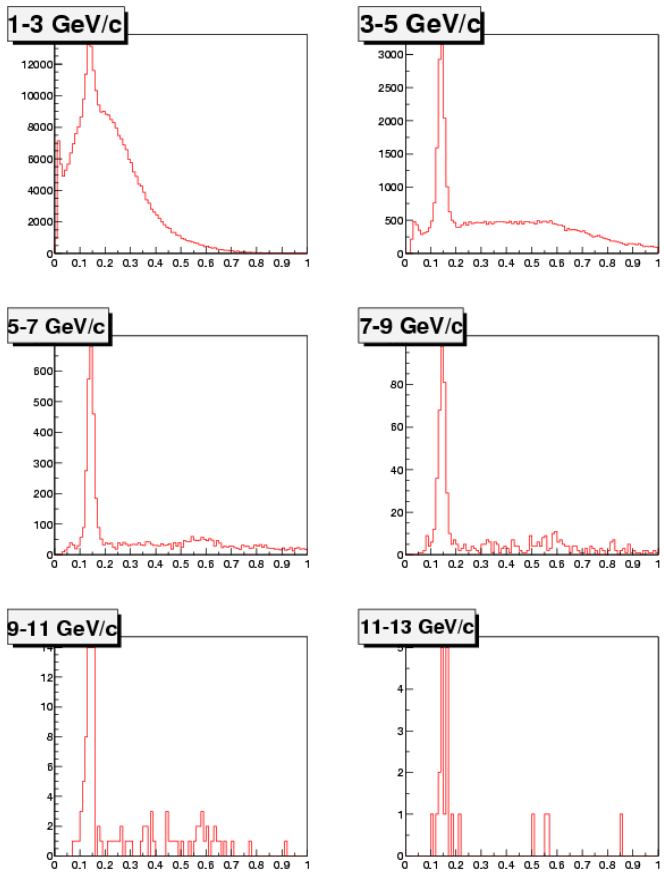


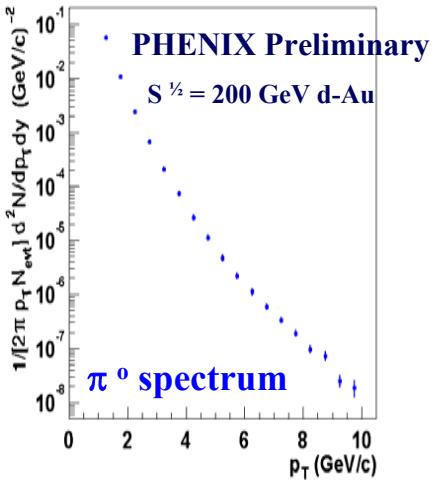
Particle ID Detectors: EM Calorimeter

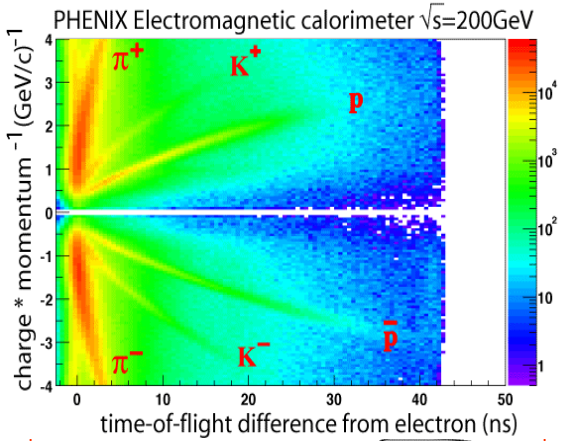
- 60 m^2 of calorimeter (6 Sectors Pb Scin, 2 Sectors PbGlass)
- Very Fine Segmentation .01 x .01 ($\Delta\Phi$ x $\Delta\eta$)
- Timing $\sigma_t \sim 340$ ps Pb Scin $\sigma_t \sim 600$ ps Pb Glass
- $\sigma_E = 10\%/\sqrt{E}+6.5\%$ Pb Scin, $\sigma_E = 8.5\%/\sqrt{E}+9.0\%$ Pb Glass

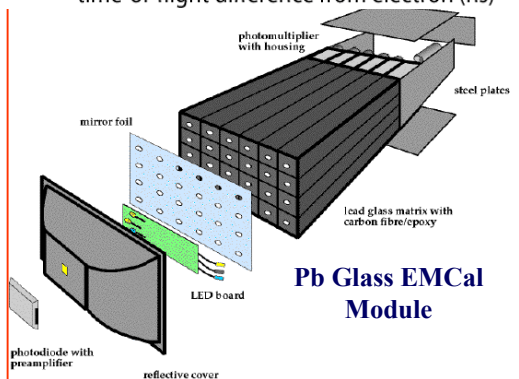
24,768 channels total, all PMTs

π^0 's from d Au events









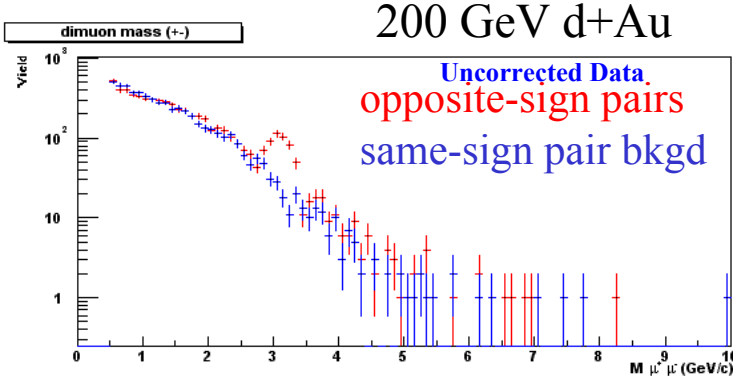
Pb Glass EMCal Module

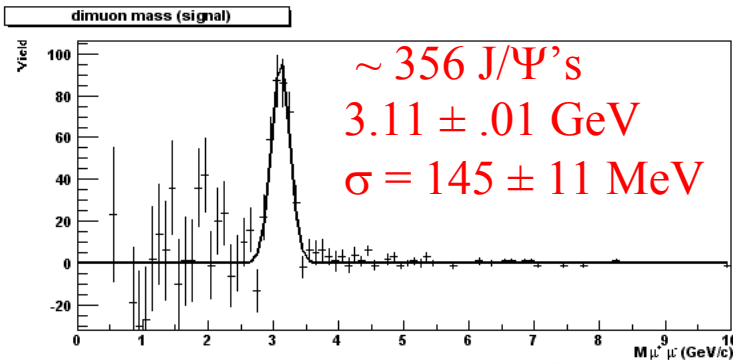
PHENIX Muon Arms

- 3 CSC tracking stations/ Muon spec. arm
- Each CSC station has a pos. resolution of σ_x=100 μm
- 20k elec. channels/ arm
- 5 layers of steel absbr plate interleaved w/ 5 layers of larocci tubes (2x,2y 4plns/layer)
- Active cross section of each wall 10m x 10m

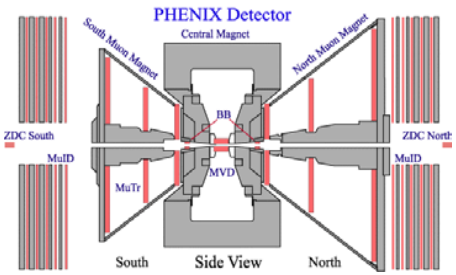
North

200 GeV d+Au



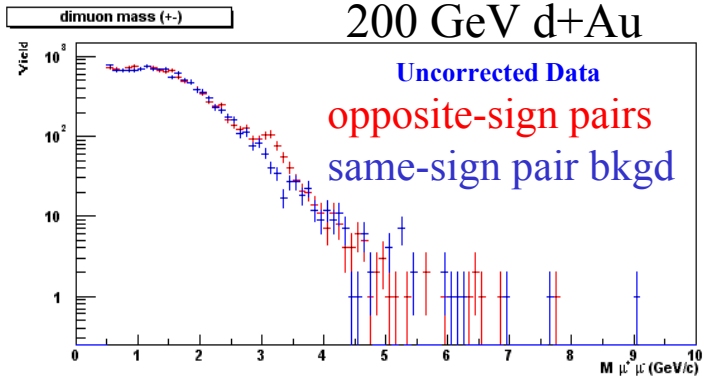


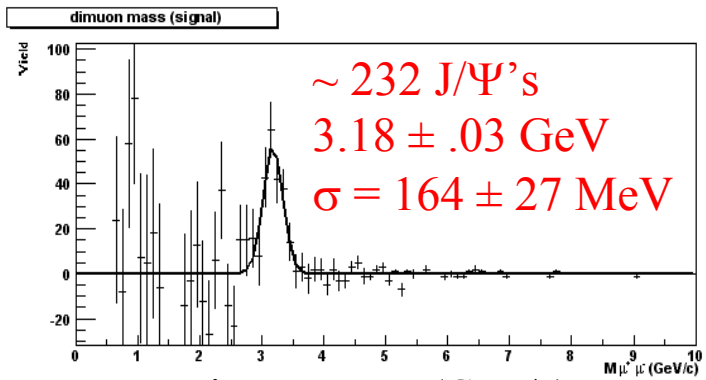
Dimuon Mass (GeV/c)



South

200 GeV d+Au





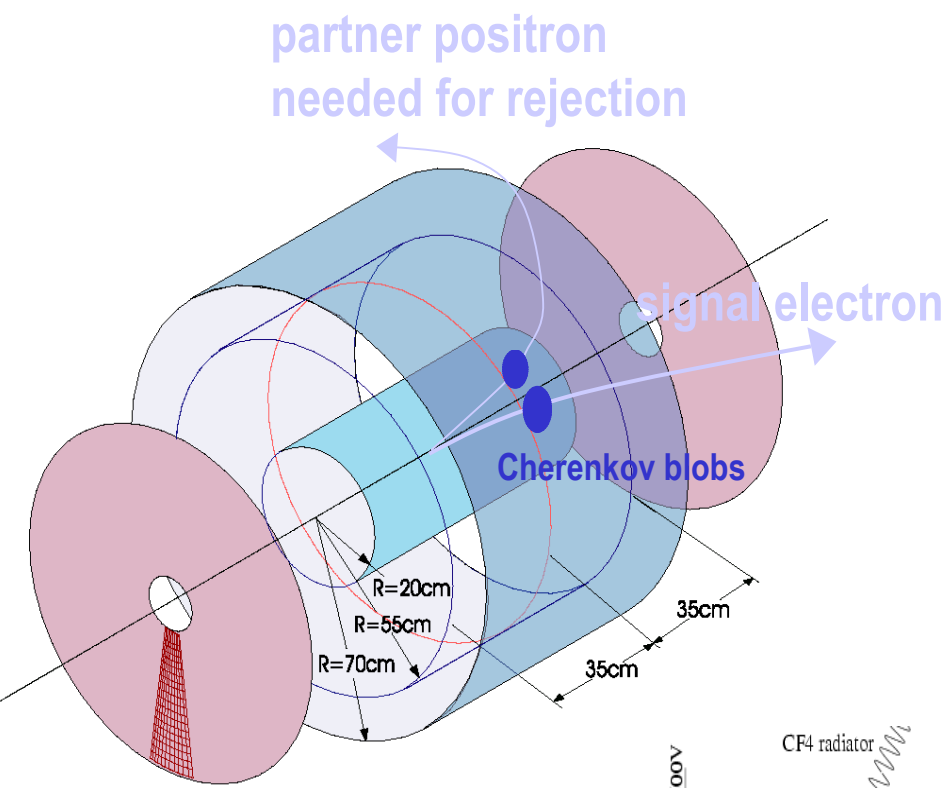
Dimuon Mass (GeV/c)

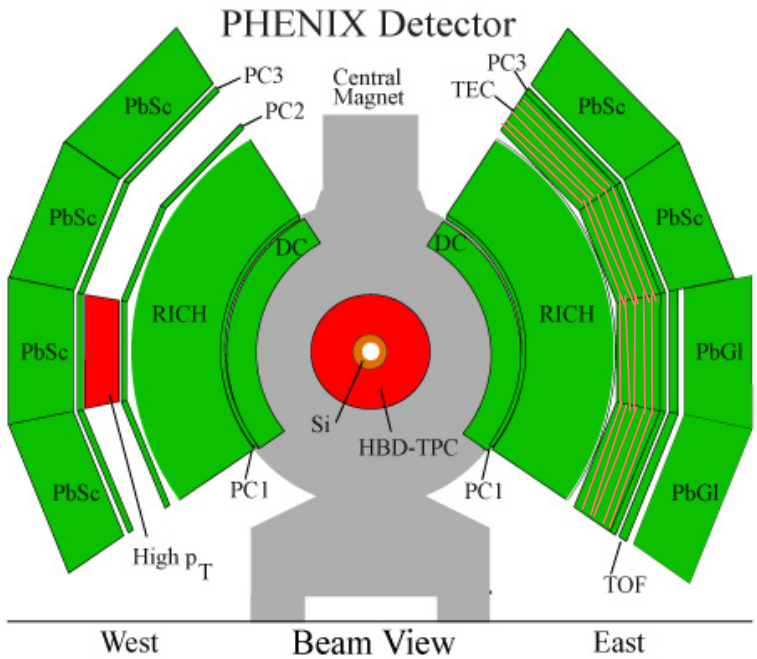
What is in the Future for the RHIC Experiments?

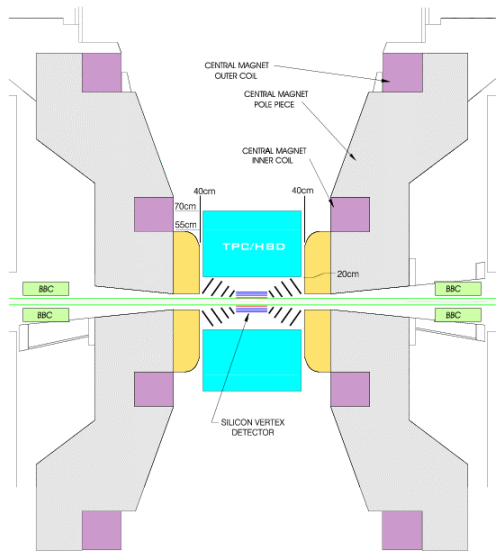
Expect RHIC 10X luminosity upgrade by 2010-2012. Need to upgrade to exploit new physics discoveries and to handle increased luminosity.

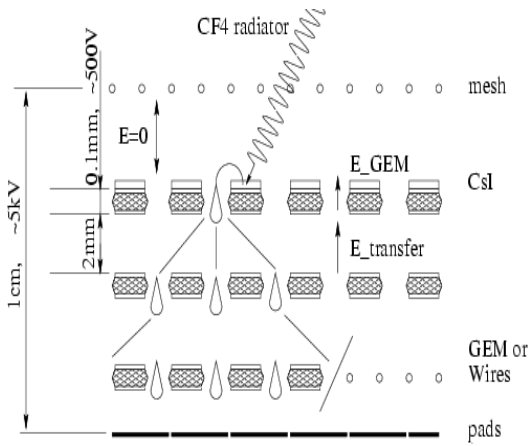
- **Si Vertex detectors for tracking and displaced vertices**
- **GEM technology**
  - **micro-TPC's**
  - **Hadron-blind detectors (GEM's with CsI doping)**
- **More calorimeter coverage**
  - **Both EM and hadronic**
- **Additional Time of Flight**
  - **mRPC's for both PID and triggering**

PHENIX Detector Upgrade





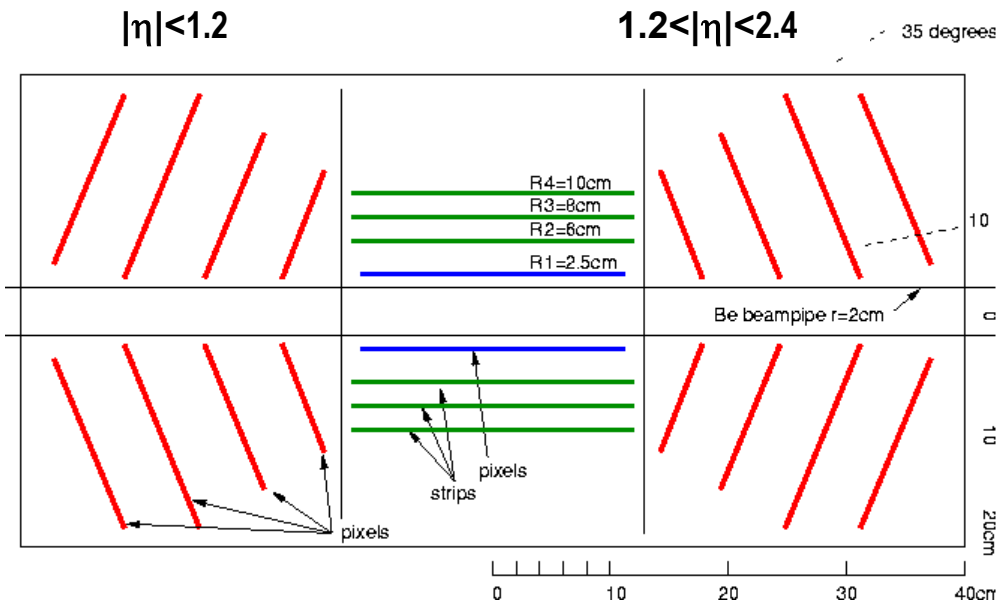


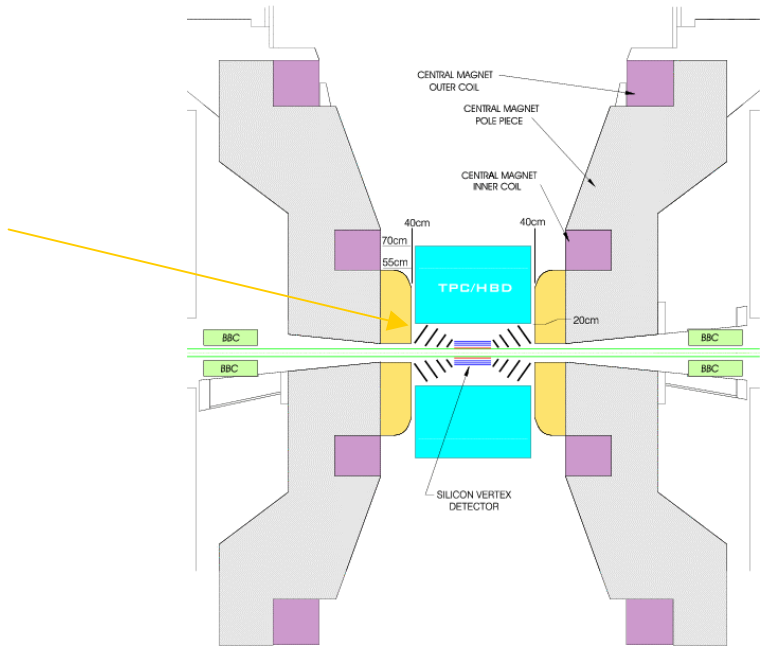


Hadron-blind Detector

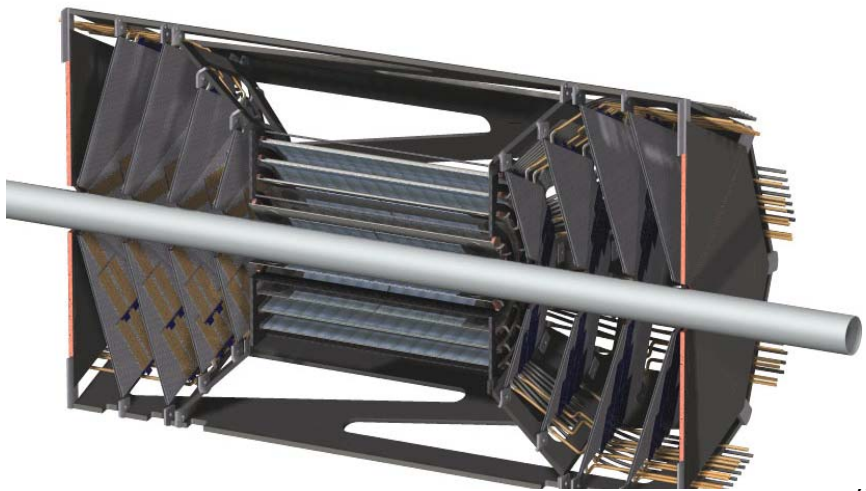
- Triple-GEM w/ CsI doping.
- CF4 radiator gas

Silicon Vertex Tracker (VTX)



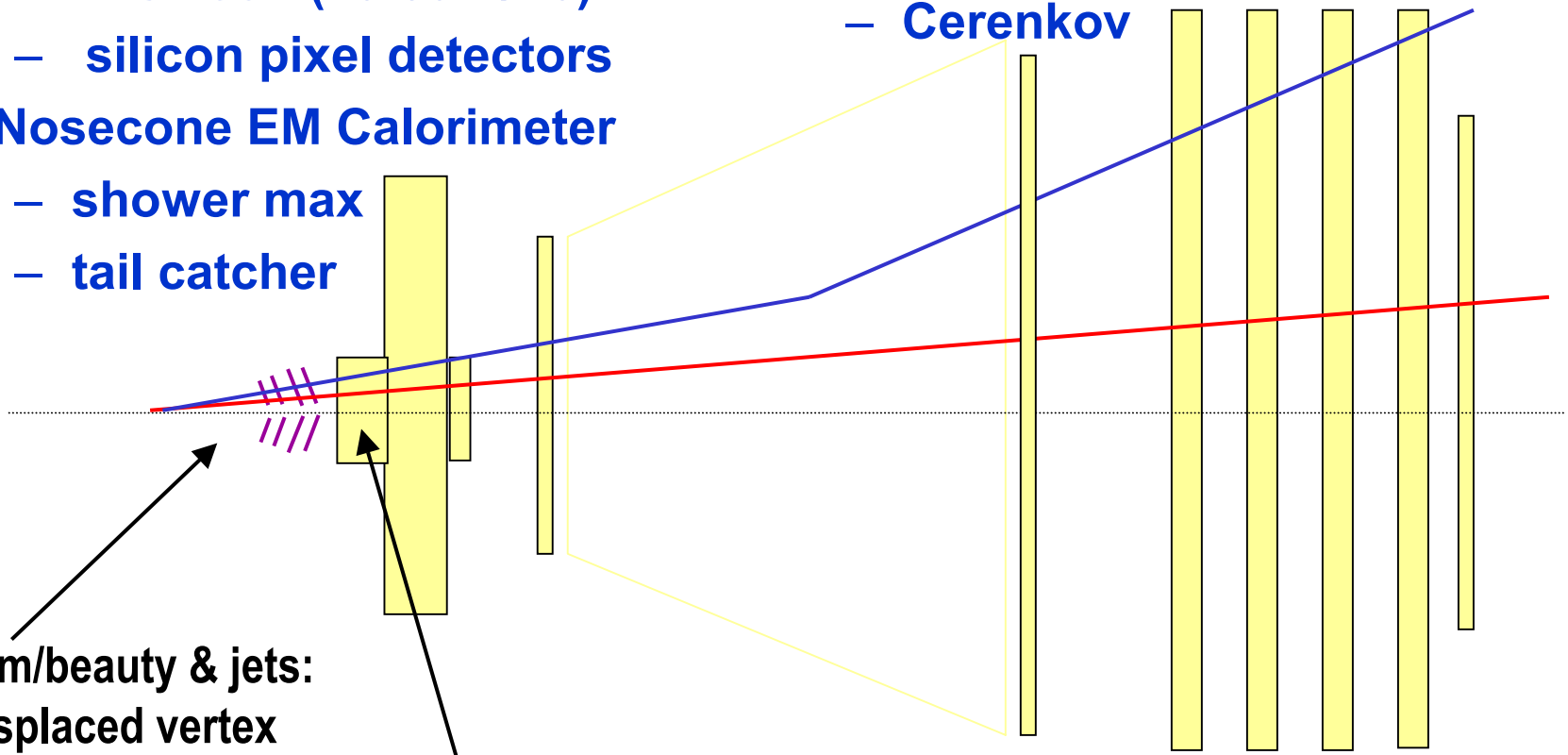


Pixel barrel
Strip barrels
Endcap Pads



Forward Upgrade Components

- Endcap Vertex Tracker
  - W-silicon (20-50 X/X0)
  - silicon pixel detectors
- Nosecone EM Calorimeter
  - shower max
  - tail catcher
- Muon trigger
  - U-tracker (MuTr or new)
  - D-tracker (timing with RPC's?)
  - Cerenkov

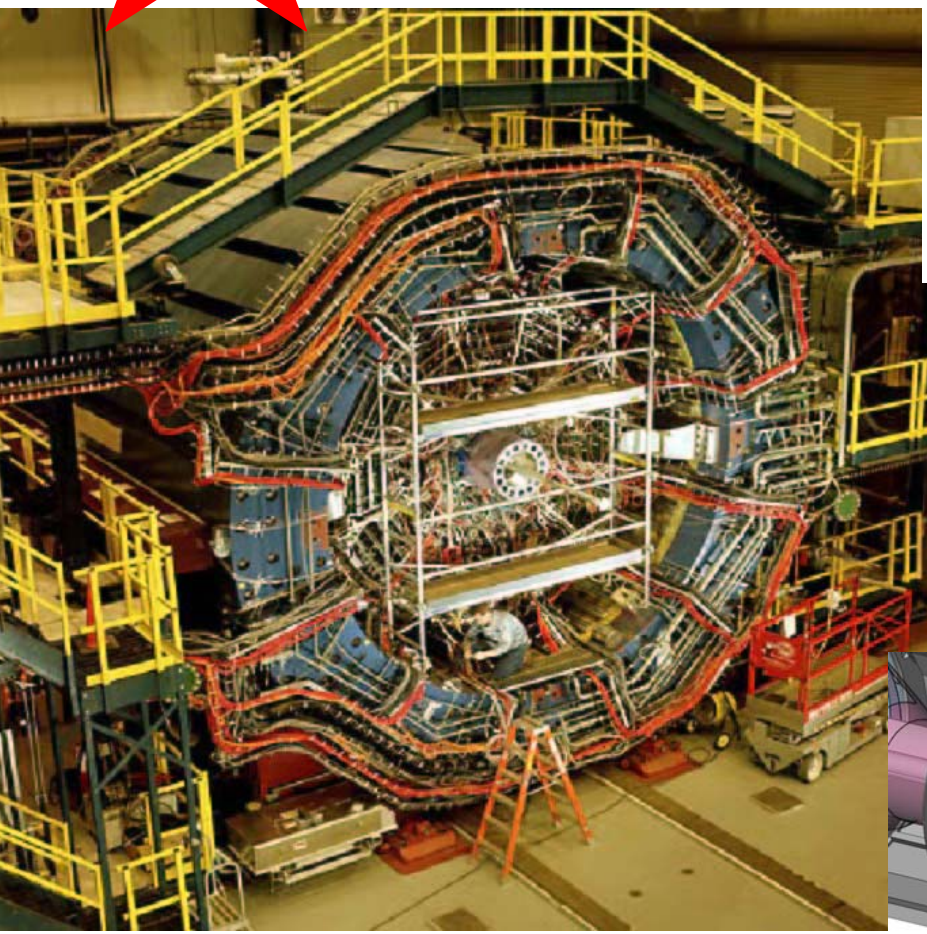


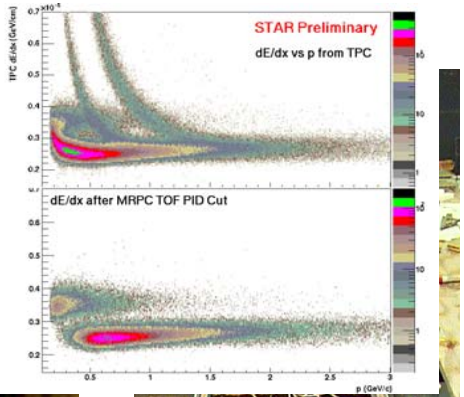
charm/beauty & jets:
displaced vertex

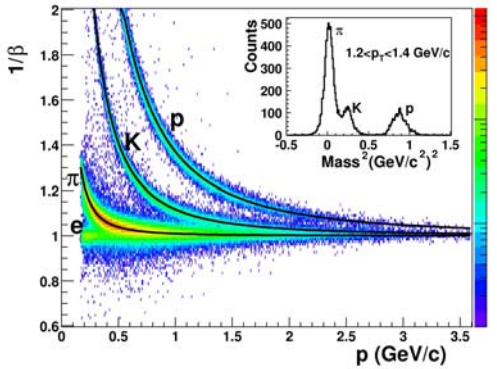
γ,γ-jet,W,π^0,η,χ_c:
calorimeter

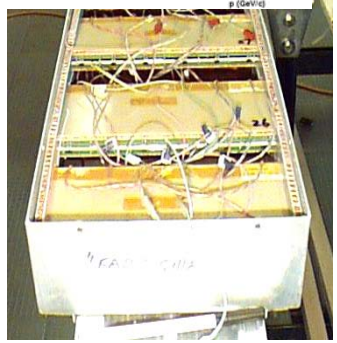
W and quarkonium:
improved μ-trigger rejection

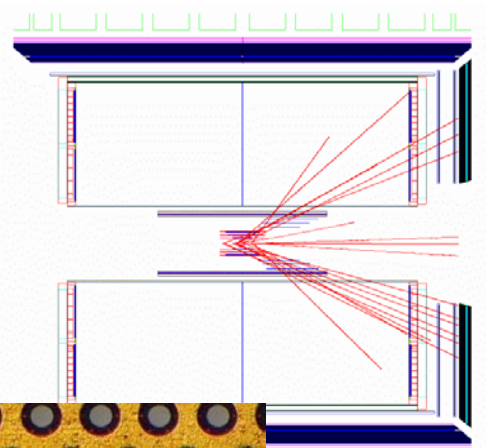
STAR Detector Upgrades

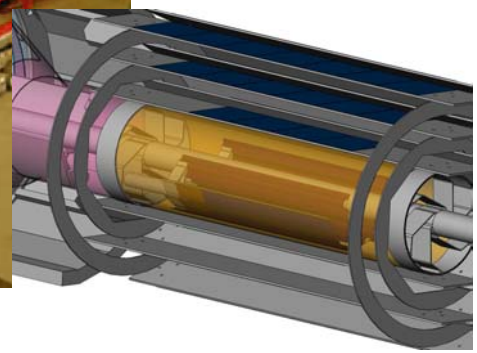


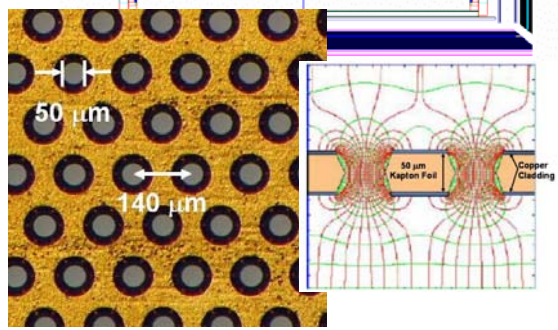






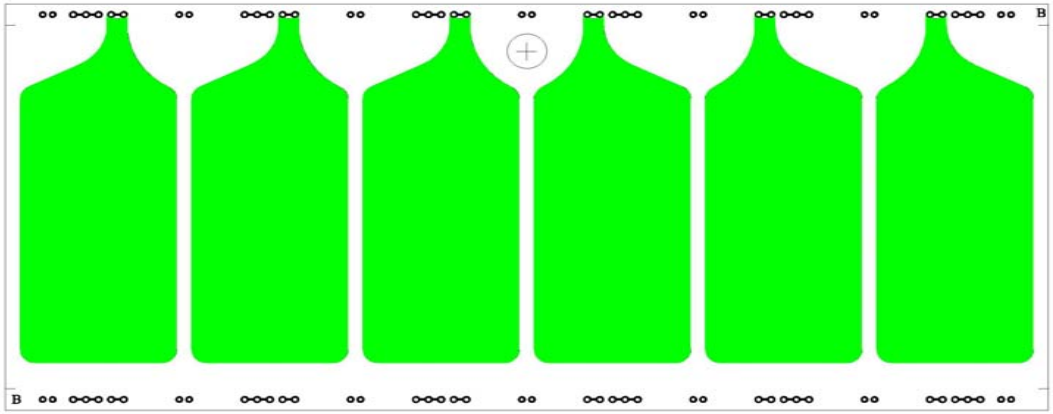


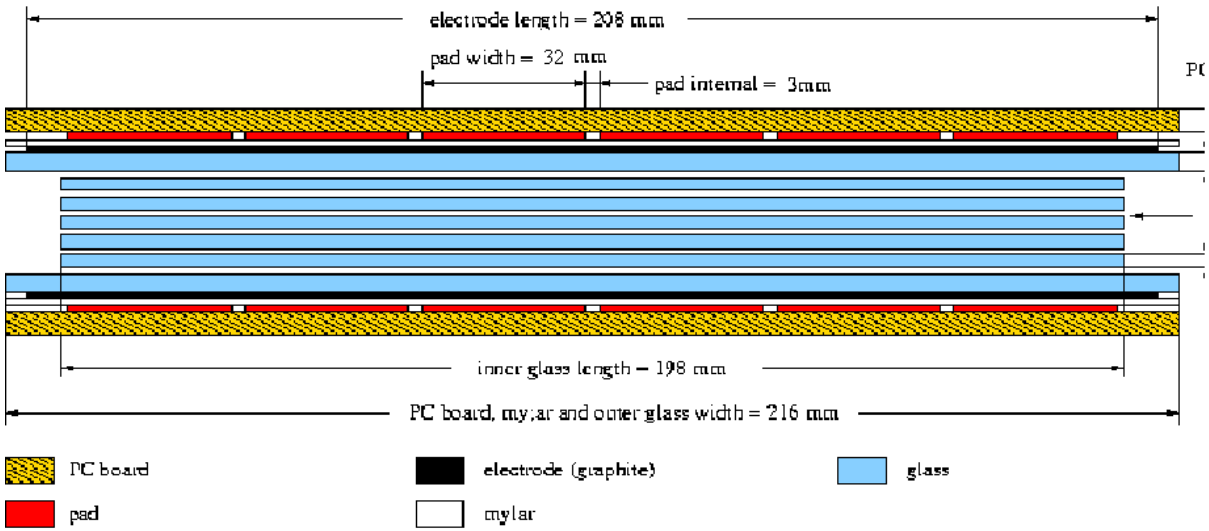




Multigap Resistive Plate Chamber

MRPC Technology developed at CERN





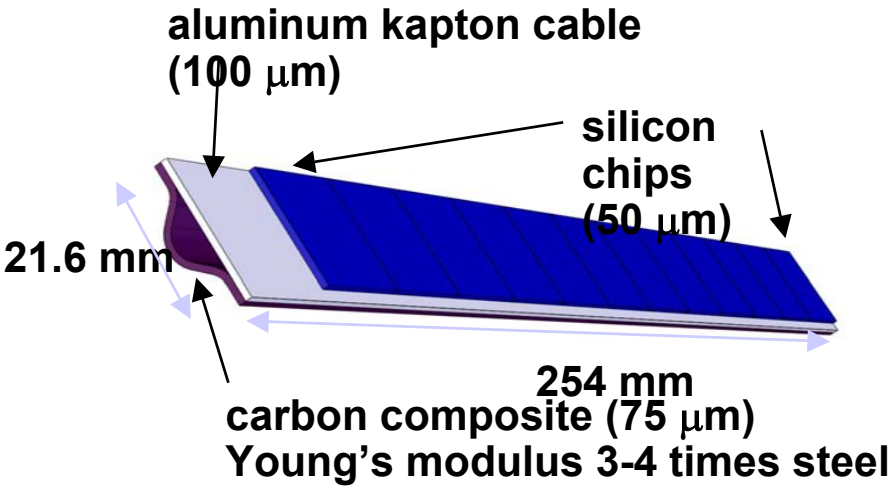
Read out pad size：
3.15cm×6.3cm

gap：6×0.22mm

95% $C_2H_2F_4$
5% Iso-butane

3800 modules, 23,000 readout chan. to cover TPC barrel

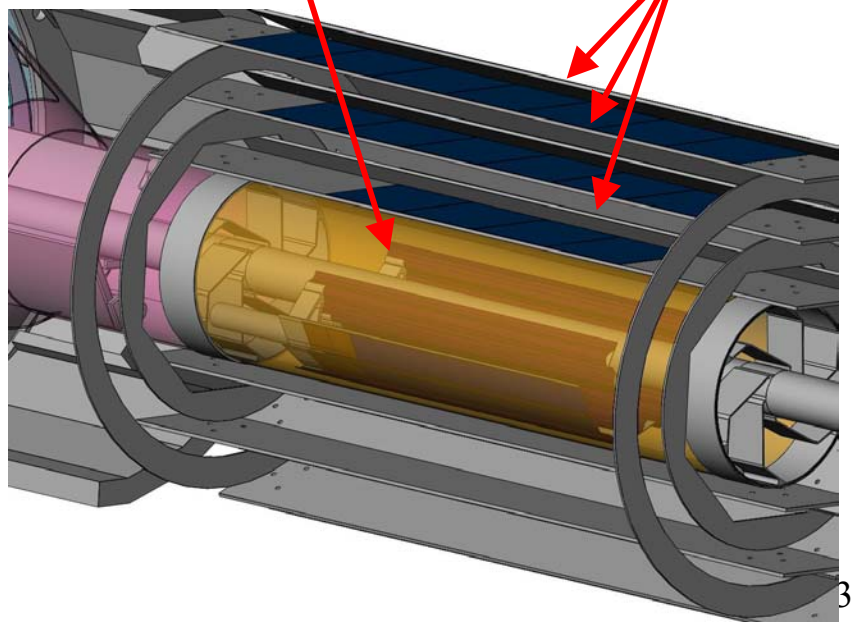
Thin stiff ladder concept



Mechanical and integration issues are being addressed:

Two Layers of APS

Existing Silicon



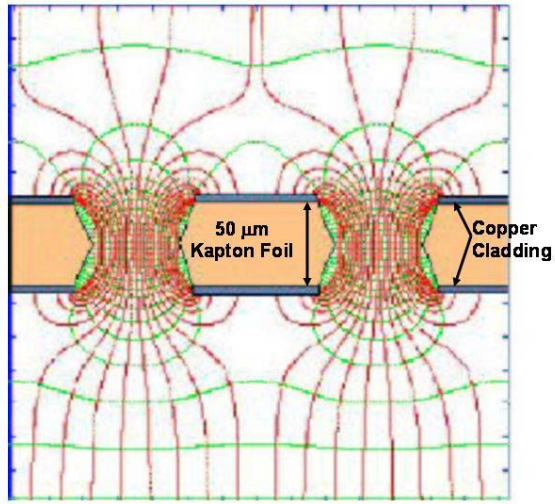
Integration volume and rapid insertion/removal being studied using modern 3-D modeling tools.

Gas Electron Multiplier

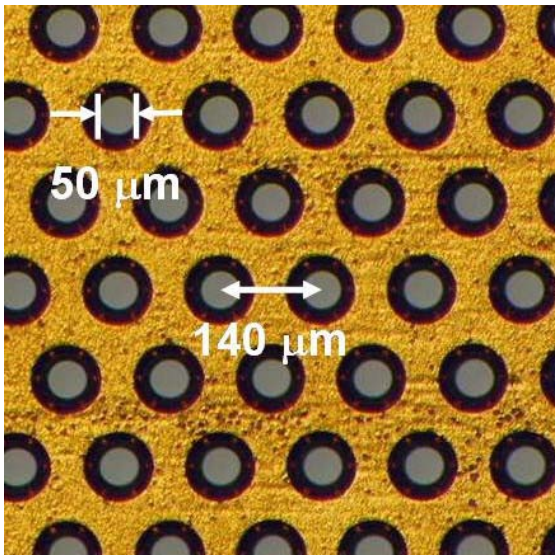
GEM

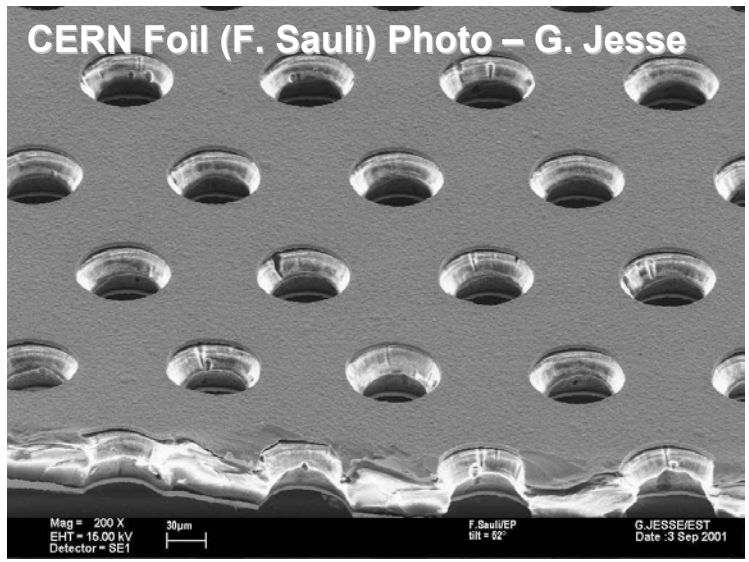
Used for micro-TPC readout

A micropattern structure produced in 50μm thick copper clad kapton using lithographic techniques.
55μm holes on ~140μm centers
Gain up to ~10^3 for single foil



3M Foil (J. Collar) Photo – Bo Yu, BNL





Conclusion

- **RHIC is in the middle of its fourth year of physics runs**
- **The RHIC accelerator is performing very well. It has reached its design luminosity in AuAu and is delivering a broad selection of beam species and energies to the experiments.**
- **There has been significant physics production to date. The variety of physics results is remarkable.**
  - **AuAu, pp, dAu data has been used to address physics topics of:**
    - **QGP and hot, high density matter**
    - **Spin Structure of the proton (A_{LL}, single spin asymmetries)**
    - **Structure function physics (especially at high gluon densities)**
- **Planning for Upgrades to the large RHIC experiments has started. R&D has begun.**
- **We have a lot to do in the next few years**